Volume XLIII May 1948 Number 3

Economic Geology

and the Bulletin of the Society of Economic Geologists

STATE COLLEGE OF AGRICULTURE AND APPLIED SCIENCE LIBRARY JUN 7 1948 MANHATTAN KANSAS

CONTENTS

The Hydrothermal Alteration of Feldspars at 250° to 400° C. ..... *Thomas F. O'Neill* 167

Tungsten Mineralization at the Ima Mine, Blue Wing District, Lehmi County, Idaho ..... *Alfred L. Anderson* 181

Variable Coalification: The Processes Involved in Coal Formation ..... *James Morton Schopf* 207

Review of the Mineral Industries of Latin America ..... *Sumner M. Anderson* 226

Discussion and Communications:

The Genesis of Intrusive Magnetite and Related Ores ..... *Charles Henry White* 232

Reply by ..... *S. J. Shand* 233

Reviews:

Geology and Ore Deposits of the Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico (Lasky) ..... *Edson S. Bastin* 234

Rocks and Rock Minerals (Pirsson and Knopf) ..... *Esper S. Larsen, Jr.* 235

Books Received ..... *Alan T. Broderick* 236

Scientific Notes and News 239

PUBLISHED SEMI-QUARTERLY

Five Dollars a Year, One Dollar a Copy

THE ECONOMIC GEOLOGY PUBLISHING COMPANY

Printed by Lancaster Press, Inc., Prince and Lemon Streets, Lancaster, Pa.

Entered as second-class matter, March 30, 1906, at the Post Office at Lancaster, Pa., under the Act of Congress of March 3, 1879

Economic Geology

and the

Bulletin of the Society of Economic Geologists

Issued Semi-Quarterly and sent to subscribers on or about the following dates: February 1, March 15, May 1, June 15, August 1, September 15, November 1, December 15.

Manuscripts for publication should be sent to the Editor, **ALAN M. BATEMAN**, at **Yale University, Yale Station, New Haven, Conn.** It is requested that contributors exercise care in writing *scientific* and *proper names*. References to other publications should be in accordance with the forms used in the pages of this journal. The manuscript should be typewritten with double space lines and must be preceded by *a brief abstract*. Galley proof will be sent authors only where a request to this effect accompanies the manuscript, or when, in the editor's opinion, the subject matter is such as will require correction by the author.

Reviews should conform to the journal usage. Review Committee: The Editor, C. H. Behre, L. C. Graton, J. T. Singewald, Jr., J. Gilluly, A. F. Buddington, W. H. Newhouse.

Books and Pamphlets for review should be sent to the Editor.

Reprints. Contributors desiring reprints of their papers may obtain them by filling out the order slip which will be attached to the galley proof when it is sent to the author. Provided the order slip is received by the editor, *with the return of the proof*, 50 reprints without covers will be furnished without charge. Reprints of discussions and informal communications are not furnished free of charge except when they exceed four pages in length when 50 will be supplied without charge. Reprints of reviews are not supplied. Additional reprints will be furnished at approximately the rates given in the table below when ordered *in advance of publication*. The rates apply only to plain text, with line engravings. Papers containing folded maps or plates will be more expensive.

The following rates *do not* include free carriage. *Postage or express must be paid by the author.*

	4 pp. 1–4	8 pp. 5–8	12 pp. 9–12	16 pp. 13–16	20 pp. 17–20	24 pp. 21–24	28 pp. 25–28	32 pp. 29–32
50 copies.....	$2.75	$4.40	$6.87	$7.15	$ 9.35	$10.72	$12.37	$13.20
100 "	3.30	5.22	7.97	8.80	11.27	13.20	15.40	16.50
Additional copies per C.	1.10	1.65	2.75	3.30	3.85	4.95	6.05	6.60

For 500 copies deduct 5%; for 1000 copies or more deduct 10%. For more than 32 pages add cost per schedule to make total. Example: For 44 pages add cost for 32 pages and 12 pages. The 50 copy price is the minimum charge.

Covers: For first 50 covers, $3.80; additional 2½¢ each. Standard covers are of the same style of type and paper as the cover of the journal, and bear the title of the article and name of its author. Special printing on cover is charged for at the cost of composition.

Plates are $2.70 for the first 50 if printed on one side, and 2 cents for additional ones; printed on both sides, $4.05 for the first 50, and 3 cents for additional ones.

Note: For any reprints requiring additional composition or changes, either in text or cover, an extra charge will be made.

Single copies of reprints (without covers) of many of the articles published in volumes issued since 1926 (Vol. XXI) are available at the following prices, upon application to the Business Editor, at Urabana, Illinois.

1–4 pp.	5–8 pp.	9–12 pp.	13–20 pp.	21–28 pp.
15c	20c	25c	30c	35c
29–36 pp.	**37–44 pp.**	**45–52 pp.**	**53–60 pp.**	**61–68 pp.**
40c	45c	50c	55c	60c

Subscriptions. The price of the journal to subscribers in the United States and its dependencies is $1.00 for a single copy, or $5.00 a year for eight numbers. To subscribers in Canada, Cuba, Mexico, Spain, and countries in Central and South America, except Dutch and French Guiana, the annual rate is $5.30; to other countries, $5.75.

Forwarding. Subscribers wishing their journal to be forwarded to a new address should leave postage for that purpose with the Postmaster at their old address.

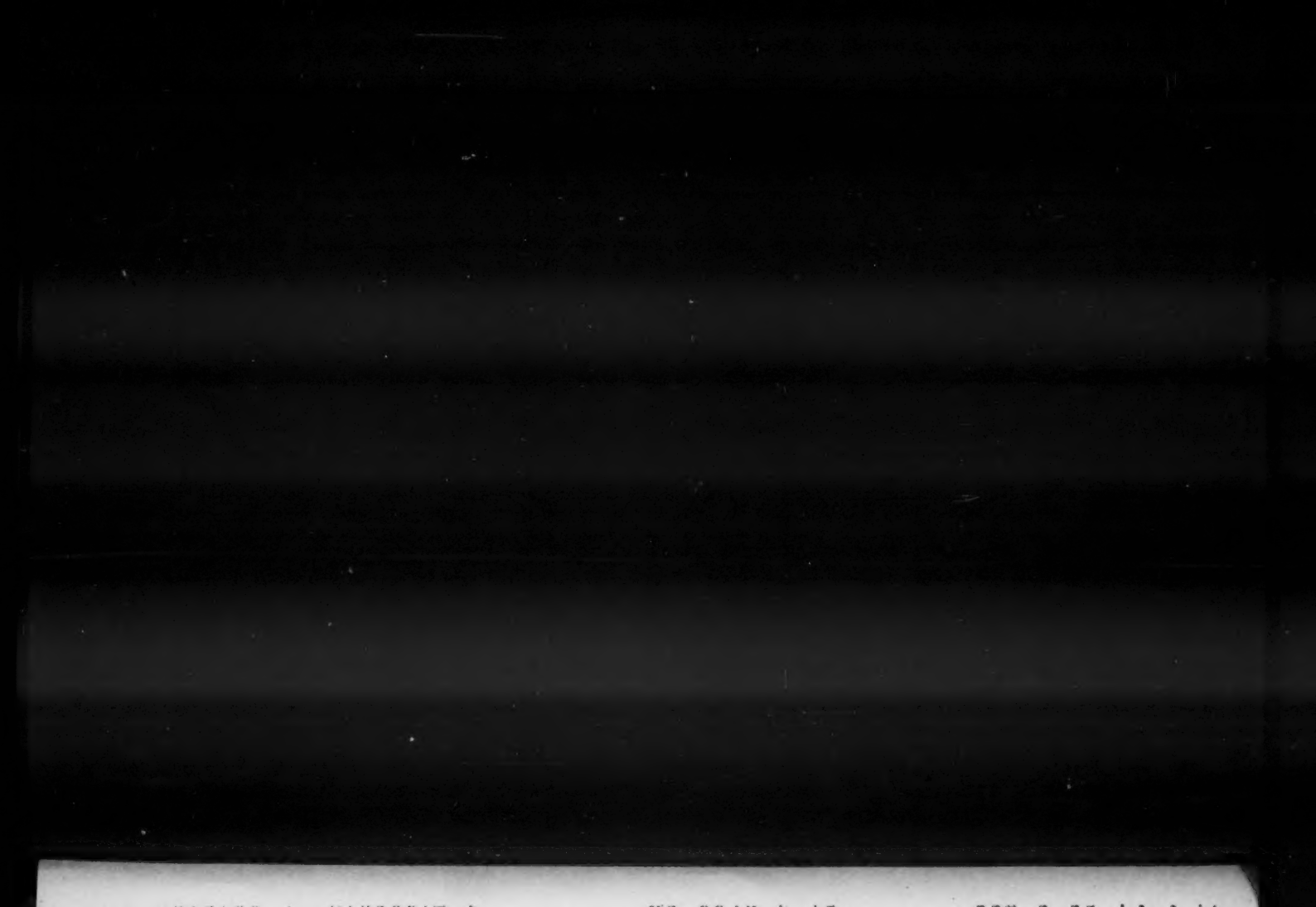
Missing numbers will be replaced without charge if claim is made within four weeks after the date of issue of the following number, provided that the neglect to receive them is not due to neglect to arrange for their forwarding.

Remittances should be made payable to the **ECONOMIC GEOLOGY PUBLISHING COMPANY**, and should be mailed to **M. M. LEIGHTON**, Business Manager, Urbana, Illinois, to whom also all **Business Communications** should be addressed.

Foreign Agents. Geo. Allen and Unwin, Ltd., No. 40 Museum St., London, W. C. 1, British Agents.

Indexed in the Industrial Art Series.

LANCASTER PRESS, INC., LANCASTER, PA.



ECONOMIC GEOLOGY

AND THE

BULLETIN OF THE SOCIETY OF ECONOMIC GEOLOGISTS

EDITOR: ALAN MARA BATEMAN
Yale University, New Haven, Connecticut

BUSINESS EDITOR: MORRIS M. LEIGHTON
Illinois Geological Survey, Urbana, Illinois

ASSOCIATE EDITORS

CHARLES KENNETH LEITH
University of Wisconsin, Madison, Wis.

D. F. HEWETT
U. S. Geological Survey, Washington, D. C.

C. N. FENNER
Geophysical Laboratory, Washington, D. C.

B. S. BUTLER
Univ. of Arizona, Tucson, Ariz.

W. E. WRATHER
U. S. Geological Survey, Washington, D. C.

HEINRICH RIES
Cornell University, Ithaca, N. Y.

OSCAR E. MEINZER
U. S. Geological Survey, Washington, D. C.

L. C. GRATON
Harvard University, Cambridge, Mass.

E. C. ANDREWS
Sydney, Australia

E. S. MOORE
University of Toronto, Toronto, Can.

A. I. LEVORSEN
Department of Geology, Stanford University, Calif.

PER GEIJER
Geological Survey of Sweden, Stockholm, Sweden

P. F. FOURMARIER
Liège, University, Liège, Belgium

ALEX. L. DU TOIT
Capetown, South Africa

M. J. S. KRISHNAN
Geological Survey, Calcutta, India

DJALMA GUIMARÃES
Instituto de Tecnologia Industrial
Belo Horizonte, Minas Gerais, Brazil

A SEMI-QUARTERLY JOURNAL PUBLISHED BY
THE ECONOMIC GEOLOGY PUBLISHING COMPANY

SOCIETY OF ECONOMIC GEOLOGISTS

THE PUBLICATIONS OF WHICH CONSTITUTE
A PART OF THIS JOURNAL

OFFICERS FOR 1948

T. M. BRODERICK .....*President*
T. B. NOLAN .....*President elect*
OLAF N. ROVE .....*Secretary*
Annandale Road, R. F. D. No. 1
Falls Church, Va.

SIDNEY PAIGE .....*Vice-Pres.*
HUGH MCKINSTRY ...*Vice-Pres. elect*
J. T. SINGEWALD, JR. .....*Treasurer*
Johns Hopkins Univ., Baltimore, Md.

Councilors

1948	*1949*	*1950*
V. T. STRINGFIELD	ERNEST F. BEAN	CARLTON D. HULIN
FRANK R. CLARK	GILBERT H. CADY	DONALD DAVIDSON
JOSEPH L. GILLSON	J. E. HAWLEY	WILLIAM CALLAHAN

Regional Vice-Presidents

DAVID WILLIAMS .....London, England .....*For Europe*
P. K. GHOSH .....Calcutta, India .....*For Asia*
HENDRICK JAN SCHUILING ..Jadotville, Belgian Congo .....*For Africa*
W. F. JAMES .....Toronto, Ont. .....*For North America*
VICTOR LOPEZ .....Caracas, Venezuela .....*For South America*
H. G. RAGGATT .....Canberra City, Australia .....*For Australia*

Executive Committee

T. M. BRODERICK, *Chairman* — SIDNEY PAIGE — T. B. NOLAN
OLAF N. ROVE — J. T. SINGEWALD, JR. — HUGH MCKINSTRY

Finance Committee

W. O. HOTCHKISS, *Chairman* — J. T. SINGEWALD, JR. — RAYMOND FRANK BAKER
ALLEN W. PINGER

Program Committee

MORLEY E. WILSON, *Chairman* — PARKER TRASK
CYRIL W. KNIGHT — ROBERT A. LAURENCE — M. M. LEIGHTON

Committee on Publications

H. E. MCKINSTRY, *Chairman* — C. S. ROSS — E. F. BEAN

Nominating Committee

THOMAS G. MOORE, *Chairman* — H. R. ALDRICH — D. H. MCLAUGHLIN

Membership Committee

DONALD M. DAVIDSON, *Chairman* — H. E. CULVER — S. W. LOHMAN
H. S. MCQUEEN — WM. F. JAMES — DAVID ST. CLAIR

LIBRARY
JUN 7 1948

ECONOMIC GEOLOGY

AND THE

BULLETIN OF THE SOCIETY OF
ECONOMIC GEOLOGISTS

VOL. XLIII MAY, 1948 No. 3

THE HYDROTHERMAL ALTERATION OF FELDSPARS AT 250° C. TO 400° C.

THOMAS F. O'NEILL.

CONTENTS.

	PAGE
Abstract	167
Introduction	167
Equipment and reagents	169
Experimental procedure	170
Experiments with albite in potassium sulfide solutions	171
Experiments with albite in acidic and basic solutions	173
Experiments with labradorite in acidic and basic solutions	176
Conclusions	178
Acknowledgments	180

ABSTRACT.

About 40 experiments with feldspars were made in K_2S solutions and in basic, neutral, and acidic concentrated solutions of NaCl or KCl at 250° C. to 400° C. Alumina or silica was added in some experiments. It was found that in the presence of excess K ions potash and soda feldspars alter to kaliophilite in solutions more basic than about 0.10 M K_2S and 0.08 N KOH. In less basic solutions and in solutions as acidic as 0.001 N potash feldspar alters to soda feldspar in the presence of an excess of Na ions. The reaction can be reversed in the presence of an excess of K ions. For a short range of concentrations more acidic than 0.001 N soda feldspar is stable for the time of the experiments, but in 0.020 N HCl soda feldspar alters to pyrophyllite. In the presence of alumina and excess K ions soda feldspar alters to muscovite in solutions as basic as 0.010 N. In the presence of silica substitution of Na in labradorite was noticeable in 0.050 N NaOH and nearly complete in 0.150 N NaOH. In less basic and in acidic solutions no Na substitution was obtained. The writer has attempted to explain some of the reactions.

INTRODUCTION.

ALKALI sulfides have long been cited as one of the important constituents in hydrothermal ore depositing solutions. As early as 1886 S. F. Emmons

stated [1] that metallic sulfides were soluble in alkali sulfides, and he suggested the possibility, at least for pyrite and galena, that the sulfides in ore deposits were transported by this means. Since that time numerous investigators have emphasized the importance of alkaline sulfides or hydrosulfides in mineralizing solutions. Fenner stated [2] that for the innumerable deposits that have been formed at moderate temperatures the medium of transportation and deposition had been a rather dilute aqueous solution, and that the presence of alkaline sulfides was regarded as a probably essential factor in increasing the solubility of the heavy metal sulfides to a sufficient degree to effect important results in transportation and deposition by hydrothermal solutions. Newhouse,[3] however, found that inclusions in galena and sphalerite specimens contained only calcium or sodium chloride, the latter salt in solutions as concentrated as 4.5 M.

In view of the extensive alteration which feldspars commonly undergo when subjected to natural hydrothermal conditions, microcline, albite, and labradorite were subjected to the artificial hydrothermal conditions of the laboratory. Gruner has recorded [4] numerous experiments conducted in an acid environment. In the present investigation the experiments were extended to neutral and basic solutions. World War II interrupted the investigation, and experiments which logically should have followed were not completed. The earliest of the present experiments were made with solutions of potassium monosulfide. This reagent hydrolyzes in aqueous solutions according to equation (1),

$$K_2S + H_2O \leftrightarrows KOH + KHS, \qquad (1)$$

and further to a lesser extent according to equation (2),

$$KHS + H_2O \leftrightarrows KOH + H_2S. \qquad (2)$$

Consequently, when a concentrated solution of potassium sulfide was diluted the hydroxyl ion concentration (determined by a test paper set using buffered solutions for comparison purposes) increased until a solution approximately 0.05 M had been reached, beyond which point further dilution resulted in a solution with decreasing hydroxyl ion concentrations. Experiments with potassium hydroxide showed that the results obtained by the use of potassium monosulfide could be duplicated, while at the same time much closer control of the basicity of the solution could be maintained. With the exception of the experiments in which potassium monosulfide was used most of the experiments were conducted in concentrated solutions of potassium or sodium chloride.

Morey and Ingerson [5] have mentioned nineteen papers which are applicable to the present experiments. Reference is made only to those which are closely pertinent to the present problem.

[1] Emmons, S. F., Geology and ore deposits of Leadville: U. S. Geol. Survey, Mon. 12, p. 563, 1886.

[2] Fenner, C. N., Pneumatolytic processes in the formation of minerals and ores: Lindgren Volume, A. I. M. E., p. 58, 1933.

[3] Newhouse, W. H., The composition of vein solutions as shown by liquid inclusions in minerals: Econ. Geol., vol. 27, pp. 419–431, 1932.

[4] Gruner, J. W., The hydrothermal alteration of feldspars in acid solutions between 300° and 400° C.: Econ. Geol., vol. 34, pp. 578–589, 1944.

[5] Morey, G. W., and Ingerson, E., The pneumatolytic and hydrothermal alteration and synthesis of silicates: Econ. Geol., vol. 32, pp. 607–760, 1937.

EQUIPMENT AND REAGENTS.

Gold-lined bombs, which have been described by Gruner,[6] were used in the experiments. The bombs used had a capacity of 51–53 cc. In all experiments they were filled with 20 cc. of solution. Taking into consideration the specific volume of water below the critical temperature the bombs were never completely filled with liquid at the temperatures of the experiments. The air above the solutions was displaced by nitrogen before closing the containers. The bombs were heated in furnaces which have been described by Norton.[7] Temperatures were determined by the use of chromel-alumel thermo-couples placed in contact with the bomb near the middle of the furnace. Thermocouple potentials were measured by a Leeds and Northrop potentiometer. The furnaces were located in a room in which the temperature remained fairly constant. Maximum temperature fluctuation in the furnaces amounted to $\pm 3°$ C. The considerable mass of the bombs should have minimized the temperature fluctuations of the solutions.

TABLE I.

ANALYSES OF FELDSPARS.

	Albite	Microcline	Labradorite
SiO_2	66.01	65.46	50.68
Al_2O_3	21.40	19.12	30.67
Fe_2O_3	n.d.	n.d.	0.21
FeO	n.d.	n.d.	0.29
MgO	n.d.	n.d.	0.42
CaO	1.74	nil	13.79
Na_2O	10.27	3.51	3.40
K_2O	0.56	11.93	0.09
Ignition	0.27	0.18	0.50
Total	100.25	100.20	100.05

Albite: Locality unknown. Grayish white moonstone cleavage fragments. Calculation of the norm indicates a composition of 86.8 per cent, albite, 8.6 per cent anorthite, and 3.1 per cent orthoclase. Ground to pass 100 mesh. L. C. Armstrong, analyst.

Microcline: Locality unknown. Grayish white cleavage fragments. Albite present in perthitic intergrowth. Calculations of the norm indicates a composition of 70.6 per cent orthoclase and 29.4 per cent albite. Ground to pass 100 mesh. L. C. Armstrong, analyst.

Labradorite: Anorthosite from Split Rock quarry, Sec. 5, T. 54 N., R. 8 W., Minnesota. Calculation of the norm indicates a composition of 28.8 per cent albite and 68.4 per cent anorthite. Ground to pass 100 mesh. R. B. Ellestad, analyst.

Three feldspars, microcline, albite, and labradorite, were used in the experiments. The microcline and albite were those used by Armstrong,[8] and the labradorite was described by Schwartz.[9] Their composition is given in Table I.

[6] Gruner, J. W., Formation and stability of muscovite in acid solutions at elevated temperatures: Am. Mineralogist, vol. 24, pp. 624–628, 1939.

[7] Norton, F. H., Accelerated weathering of feldspars: Am. Mineralogist, vol. 22, p. 45, 1937.

[8] Armstrong, L. C., Decomposition and alteration of feldspars and spodumene by water: Am. Mineralogist, vol. 25, p. 813, 1940.

[9] Schwartz, G. M., The calcic feldspar deposits of Minnesota: Am. Ceramic Soc. Bull. 16, pp. 471–476, 1937.

The first experiment was made with a potassium sulfide solution prepared from "Potassa sulfurated Merck—U.S.P." No other potassium sulfide could be obtained. This reagent was not satisfactory, since the solution prepared from it actively corroded the gold lining of the bomb. For the other experiments a potassium sulfide solution was freshly prepared from potassium hydroxide just before filling each bomb. In order to obtain more stable solutions of potassium sulfide the following procedure was used.[10] A solution of potassium hydroxide slightly more than 1.0 N was made from distilled water which had been boiled vigorously for fifteen minutes. To a liter of this solution was added 50 to 80 cc. of a concentrated solution of milk of lime, as directed by Kolthoff.[11] The solution was then shaken energetically for one hour, tightly stoppered, and the precipitate allowed to settle for 72 hours. The clear solution was then siphoned off and standardized. The solution contained at most only 1 to 2 milligrams of calcium per liter. A new solution was prepared periodically to minimize contamination from the glass container. When potassium sulfide was needed a known volume of the potassium hydroxide solution was measured into a flask from a burette. Washed hydrogen sulfide was then passed through the solution for one hour, after which a volume of potassium hydroxide solution equal to the original was added. The solution was immediately placed in the bomb.

In addition to potassium chloride, sodium chloride, potassium hydroxide and sodium hydroxide of analytical grade, two other reagents were occasionally used. One of these was aluminum hydroxide (Merck), which contained 37 per cent H_2O and gave an X-ray pattern of bayerite. The other was "silicic acid" (C. P. Mallinckrodt), which contained 10.36 per cent H_2O and was amorphous to X-rays.

EXPERIMENTAL PROCEDURE.

In each experiment 200 mg of a feldspar were placed in the bomb. When potassium or sodium chloride was also used in the experiment 0.06 gram equivalents were placed in the bomb in solid form. When exactly 20 cc. of potassium or sodium hydroxide, hydrochloric acid, or distilled water were added this gave a solution which was approximately 3.0 molal with respect to either potassium or sodium chloride. After completion of an experiment the solid material in the bomb was washed until no test for chloride could be obtained, and then air dried. In some cases the silica content of the solution was determined. The air dried powders were X-rayed in precision cameras with radii of 57.3 mm. Unfiltered Fe radiation was used. Sharp, distinct patterns were obtained in virtually all cases.

A microscopic examination was also made of each powder to determine the extent of recrystallization or secondary growth. Each product identified by X-rays was checked by optical means, and three products, presumably

[10] Potassium sulfide in solutions containing dissolved carbon dioxide is decomposed to potassium carbonate and hydrogen sulfide. Oxygen, free from carbon dioxide, oxidizes potassium sulfide to potassium sulfite. In the presence of both carbon dioxide and oxygen potassium sulfide is converted to potassium thiosulfate.

[11] Kolthoff, I. M., Einfache Herstellung von carbonat-freier Lauge: Zeitschr. anal. Chemie, vol. 61, p. 48, 1922.

artificial silicates, which could not be identified by X-rays, were studied microscopically.

EXPERIMENTS WITH ALBITE IN POTASSIUM SULFIDE SOLUTIONS.

Ten experiments conducted with albite and potassium sulfide solutions gave the results tabulated in Table II. In experiment No. 1 albite was subjected to a solution prepared from "Potassa sulfurated Merck—U.S.P." The albite was unaltered, but the resulting solution contained 4,010 parts per million of gold. This amount is more than twice the maximum obtained by Ogryzlo [12] at the same temperature by means of sodium hydrosulfide solutions. The remainder of these experiments were conducted in potassium sulfide solutions prepared as previously described.

TABLE II.

HYDROTHERMAL EXPERIMENTS WITH ALBITE AND POTASSIUM SULFIDE SOLUTIONS.

No.	Temp. ° C.	Time, hours	Molarity of K_2S sol'n	Products	Remarks
1	300	216	0.500*	Albite	* K_2S (Merck-U.S.P.) Gold in sol'n 4,010 p.p.m.
11	250	440	0.430	Orthoclase, kaliophilite and "A"	Kaliophilite as hexagonal prisms. SiO_2 in sol'n 2,285 p.p.m.
2	300	216	0.450	Orthoclase and kaliophilite	Kaliophilite as hex. plates and prisms. SiO_2 in sol'n 1,910 p.p.m.
4	360	216	0.450	Kaliophilite, orthoclase and "A"	Kaliophilite as hexagonal plates
7*	350	166	0.430	Kaliophilite and microcline	* Microcline used in place of albite
10	400	162	0.430	Kaliophilite, orthoclase and "A"	Kaliophilite as hexagonal plates SiO_2 in sol'n 4,090 p.p.m.
6	350	212	0.100	Kaliophilite and orthoclase	Kaliophilite as hexagonal plates
19	400	150	0.050	Orthoclase	Secondary growths and euhedral crystals
13	400	189	0.430	Kaliophilite	Al_2O_3:SiO_2 = 1:6
32	400	166	0.025	Kaliophilite and "B"	100 mg of bayerite added

Only two mineral products, orthoclase and kaliophilite ($KAlSiO_4$), resulted over a considerable range in concentration of the reagent. The alteration produced apparently is dependent on the concentration of the solution, and is as follows: albite → orthoclase → kaliophilite. The first step in the alteration of albite was complete, as evidenced by the fact that no residual albite remained in any of the experiments. The reaction was one of double decomposition according to equation (3),

$$NaAlSi_3O_8 + KOH \rightarrow KAlSi_3O_8 + NaOH. \qquad (3)$$

[12] Ogryzlo, S. P., Hydrothermal experiments with gold: ECON. GEOL., vol. 30, pp. 400–424, 1935.

The degree of completion which this reaction attains is undoubtedly dependent, at any given temperature, on the effective concentration of potassium ions. However, the rate of reaction is dependent, at any given temperature, on the pH of the solution. The effect of pH on the rate of reaction will be brought out more clearly in the description of subsequent experiments. In the very basic potassium sulfide solutions the reaction proceeded so rapidly at 400° C. that no attempt was made to determine any further the effect of pH.

Microscopically the albite was seen to be considerably altered. The transparent, angular fragments had acquired a brownish hue and a marked decrease in transparency. The brown hue may be caused by colloidal gold. Many suggestions of euhedral feldspar crystals could be found in all of the samples, but in experiment No. 19 euhedral crystals were recognized. The crystals were very small under a magnification of 360 ×, but crystal forms of orthoclase were distinct. Secondary growth, only suggested in other experiments, was very evident in this one.

Orthoclase is the stable alteration product in dilute potassium sulfide solutions, but when a concentration of approximately 0.10 M is reached the orthoclase is further altered to kaliophilite. The possible reaction in this case is one of decomposition according to equation (4),

$$KAlSi_3O_8 \rightarrow KAlSiO_4 + 2SiO_2. \qquad (4)$$

In none of the experiments was all of the orthoclase altered to kaliophilite, and it is not known whether equilibrium was reached in any of the experiments. On the basis of the silica content of the resulting solutions the alteration of orthoclase to kaliophilite in experiments Nos. 11, 2, and 10 was 45 per cent, 41 per cent and 89 per cent respectively. If equilibrium was reached in these experiments the presence of silica in the initial solution would cause equilibrium to be reached at an earlier stage in the reaction. This presence of silica from an outside source might make albite stable in somewhat more basic solutions than these experiments indicate.

The addition of alumina to the system makes albite less stable. Experiment No. 32 was carried out under conditions which normally would have resulted in the formation of orthoclase alone (*cf.* experiment No. 19). However, the addition of 100 mg of alumina shifted the equilibrium to such an extent that only kaliophilite and an artificial silicate were obtained. This is no doubt to be explained by the fact that the silica dissolved by the potassium sulfide solution or released by the formation of kaliophilite, which probably proceeds to a very slight extent even in extremely dilute silica-free solutions, was immediately removed by being combined into additional kaliophilite or the artificial silicate "B," thereby causing equation (4) to move completely to the right.

To test the possibility that the alteration of albite did not take place as suggested, albite → orthoclase → kaliophilite, microcline was substituted for albite in experiment No. 7, in which a partial alteration to kaliophilite was obtained. An attempt to synthesize orthoclase by subjecting bayerite and "silicic acid," mixed in the molecular proportions of orthoclase, to 0.430 M potassium sulfide solution resulted only in kaliophilite (experiment No. 13).

This experiment shows that kaliophilite will always be the end product provided sufficient potassium and aluminum ions are present.

Kaliophilite has been produced by many investigators by treating kaolinite or muscovite with basic solutions, commonly potassium carbonate or hydroxide. The lowest temperature at which it has been obtained is 200° C., in an experiment in which E. Gruner [13] treated muscovite with excess potassium hydroxide for one hundred hours. An experiment at 100° C. produced no kaliophilite. It therefore seems probable that kaliophilite could be produced by the action of potassium sulfide solutions on albite at temperatures at least as low as 200° C.

The kaliophilite obtained in the experiments occurred as small hexagonal basal pinacoidal plates or hexagonal prisms. The two forms appear to be dependent on the temperature of formation, since simple hexagonal prisms were obtained at 250° C. and 300° C., while hexagonal plates were formed at and above 300° C. Kaliophilite in nature occurs as hexagonal prisms or acicular crystals. It has not been recognized as a product of hydrothermal alteration.

Two additional products, probably hydrous artificial silicates, were found in several of the experiments. These products were designated as product "A" and product "B." Product "A" occurred as acicular crystals whose length-breadth ratio commonly reached 10:1 to 20:1, more rarely 100:1. The crystal system is unknown and the crystal terminations are indeterminate. The crystals show parallel extinction and positive elongation. Their birefringence can only be roughly approximated, but it is probably moderately high. The index of refraction normal to the elongation is in the range 1.62–1.63. Masses of the fibers were selectively sorted from the powder and an X-ray powder diagram was made from them. Only lines of kaliophilite were obtained. Product "B" is probably tetragonal. The only crystal forms which appear to be present are the prism and the c(001) pinacoid. The crystals show parallel extinction and negative elongation. N_ϵ 1.505–1.509, N_ω 1.506–1.510. No lines were found in the X-ray powder diagram which could be assigned to this product.

EXPERIMENTS WITH ALBITE IN ACIDIC AND BASIC SOLUTIONS.

Additional experiments with albite were made in which dilute potassium hydroxide solutions or dilute hydrochloric acid solutions were used. In each of these experiments potassium ions were furnished in large excess by potassium chloride. The results are tabulated in Table III.

In the presence of excess potassium ions albite was partially altered to orthoclase at 350° C. in neutral solutions (experiment No. 8). When this experiment was repeated at 400° C. alteration to orthoclase was complete (experiment No. 12). Complete alteration of albite to orthoclase was also obtained in weakly basic solutions (experiment No. 16). However, in weakly acidic solutions the rate of alteration is decreased at 400° C., until in

[13] Gruner, E., Untersuchungen an Alkali-Aluminium-Silicaten. I. Synthetische Studien am Nephelin: Zeitschr. anorg. Chemie, vol. 182, pp. 319–331, 1929.

TABLE III.

HYDROTHERMAL EXPERIMENTS WITH ALBITE IN ACIDIC AND BASIC SOLUTIONS.

No.	Temp. ° C.	Time, hours	Grams KCl	Grams $Al(OH)_3$	Normality of solutions		Products	Remarks
					HCl	KOH		
8	350	192	4.46		neutral		Orthoclase and albite	
12	400	200	4.46		neutral		Orthoclase	
35	400	164	4.46		0.0005		Albite and orthoclase	
31	400	162	4.46		0.005		Albite	
27	400	167	4.46		0.020		Albite and pyrophyllite	
21	400	166	4.46		0.100		Albite and pyrophyllite	
16	400	164	4.46			0.005	Orthoclase	
20	400	166	4.46			0.080	Orthoclase and kaliophilite	
14	400	210	*		neutral		Albite	Used orthoclase from No. 12. * 3.50 gms. NaCl
23	400	167	*		neutral		Albite	* 3.0 molal respect to Cl^-, Na:K = 9:1
34	400	163	*		neutral		Albite	* 3.0 molal respect to Cl^-, Na:K = 2:1
30	400	166	4.46	0.100		0.010	Muscovite and kaliophilite	
36	400	164	4.46	0.100		0.050	"C" and kaliophilite	Recovered only 5 cc
38	400	161	4.46			0.050	Kaliophilite and "C"	
22	400	166					Muscovite, orthoclase and boehmite	Synthesis of muscovite 141.0 mg K_2CO_3 399.7 mg $Al(OH)_3$ 402.0 mg $SiO_2 \cdot \frac{1}{2}H_2O$

solutions stronger than about 0.001 N hydrochloric acid no alteration could be observed. Why the substitution of potassium for sodium should cease at an acidity considerably below that at which the alkalies are appreciably leached from feldspars is not clear. Albite was stable in more acidic solutions (experiment No. 31), at least for the times employed in the experiments, but when the normality of the acid reached 0.020 N pyrophyllite was formed in large enough quantities to be detected. Pyrophyllite was still produced by 0.10 N hydrochloric acid in experiment No. 21. Gruner has reported[14] numerous experiments in 0.105 N hydrochloric acid in which pyrophyllite is

[14] Gruner, J. W., The hydrothermal alteration of feldspars in acid solutions between 300° C. and 400° C.: ECON. GEOL., vol. 34, pp. 578–589, 1944.

one of the products, and he has discussed its range of stability. In acid solutions the alkalies of the feldspars are taken into solution as long as the acidity of the solution is maintained above a certain minimum, or the alkali content of the solution does not exceed a certain maximum. The minimum acidity required for the reaction at 400° C. is between 0.005 and 0.020 N. The reaction takes place according to equation (5),

$$2NaAlSi_3O_8 + 2HCl \rightarrow (OH)_2Al_2Si_4O_{10} + 2SiO_2 + 2NaCl. \qquad (5)$$

The results of experiments Nos. 16 and 20 agree with those obtained by the use of potassium sulfide solutions. In 0.005 N potassium hydroxide solutions albite altered to orthoclase, but in a 0.080 N solution some kaliophilite also was formed. The substitution of potassium for the sodium in albite is an effect of mass action. The reaction is completely reversible in neutral solutions at 400° C., according to equation (6),

$$NaAlSi_3O_8 + K^+ \leftrightarrows KAlSi_3O_8 + Na^+. \qquad (6)$$

The orthoclase produced in experiment No. 12 was reconverted to albite in experiment No. 14 by subjecting it to a 3.0 M solution of sodium chloride for the same length of time at 400° C. The resulting albite was very fine grained.

In connection with the study of the effect of mass action two additional experiments (Nos. 23 and 34) were made. These were suggested by the statement of Fenner [15] that ". . . we perceive that the potassium that is so important in substitution processes in the feldspars is not derived (except, perhaps, in small degree) from the igneous body but from carbonate attack upon feldspars of roof rock at a lower level than the bore hole attained. . . . The surprising thing (not dependent upon theory or inference) is that in the upper levels substitutions of potassium for sodium goes on until the waters are so depleted of potassium and enriched in sodium that the ratio of the two becomes 1 : 34." The solutions to which Fenner had reference were thought to have been alkaline, and as a consequence the results of the two experiments may be questioned, since neutral solutions were used. Experiments No. 23 and No. 34 in which the ratio of potassium to sodium was 1 : 9 and 1 : 2 showed no preferential substitution of potassium for sodium. Fenner suggested the possibility, however, that under near surface conditions the order of replacement might be reversed, and that the soda-rich orthoclase, associated commonly with analcite and heulandite, might be a result of the partial replacement of potassium by sodium from the solution in which their ratio is 1 : 34. The present experiments indicate such a replacement.

Gruner [16] found in acid and neutral solutions containing excess potassium ions at 400° C. that the addition of alumina resulted in the alteration of albite to muscovite. These experiments were extended to a basic environment by the writer. Albite was altered to muscovite and some kaliophilite in 0.010 N potassium hydroxide solution (experiment No. 30), but when the normality was increased to 0.050 only kaliophilite and unknown product "C" were ob-

[15] Fenner, C. N., Bore-hole investigations in Yellowstone Park: Jour. Geology, vol. 44, p. 300, 1936.

[16] Gruner, J. W.: op. cit., p. 586.

tained (experiment No. 36). This is in general agreement with the work of other investigators. Noll [17] had previously prepared muscovite in alkaline solutions at 300° C. by heating a colloidal adsorption material of the composition $K_2O.3Al_2O_3.6SiO_2.xH_2O$. This experiment was reproduced by the writer at 400° C., using potassium carbonate, bayerite, and "silicic acid" in the molecular proportions of muscovite. The solution placed in the bomb had a pH of 11. The product was largely muscovite, with some orthoclase and boehmite (AlO(OH)) (experiment No. 22).

The alteration of albite to muscovite in solutions in which the added base is less than 0.010 N may be according to equation (7),

$$NaAlSi_3O_8 + 2Al(OH)_3 + KCl \rightarrow (OH)_2KAl_3Si_3O_{10} + NaCl + 2H_2O. \quad (7)$$

It would be expected that orthoclase would be an intermediate product in such a reaction, but Gruner has shown [18] in his experiment 177 that this is not so, at least in neutral solutions. Muscovite does not seem to be stable in potassium hydroxide solutions more basic than 0.010 N, but alters to kaliophilite. The reaction may proceed according to equation (8),

$$(OH)_2KAl_3Si_3O_{10} + 2KOH \rightarrow 3KAlSiO_4 + 2H_2O. \quad (8)$$

An artificial hydrous silicate designated as product "C" occurred in experiments Nos. 36 and 38. The material was in small plates and appeared to belong to the orthorhombic system. The only crystal forms visible were the three pinacoids. The crystals showed positive elongation and parallel extinction. The indices of refraction were: N_p 1.515–1.518, N_m 1.517–1.520, and N_g 1.525 ± 0.002.

Experiment No. 36 is of interest because, due to leakage during the initial heating of the bomb, the degree of filling was only about one-quarter of that normally employed. With such a low degree of filling, slightly less than one-tenth of the volume of the bomb, no liquid phase could have been present, but only vapor and solids. However, the alteration products were the same as those obtained in a duplicate experiment in which the usual degree of filling (four-tenths of the bomb's volume) was maintained.

EXPERIMENTS WITH LABRADORITE IN ACIDIC AND BASIC SOLUTIONS.

A series of experiments was made with labradorite under conditions comparable to those just described for albite. Instead of potassium chloride, however, sodium chloride was added in all experiments to furnish a large excess of sodium ions. The results are tabulated in Table IV.

Labradorite behaved similarly to albite when treated with 0.35 N hydrochloric acid at 400° C., and was completely altered to pyrophyllite. However, when labradorite was subjected to basic solutions the sodium equivalent of kaliophilite (nepheline) did not form, but sodalite ($3NaAlSiO_4.NaCl$) resulted instead (experiment No. 37). This was probably due to the high

[17] Noll, W., Hydrothermale Synthese des Muscovits: Ein Beitrag zur Frage Serizitbildung in Tonschiefern. Nachr. Gesell. Wiss. Gottingen, Math.- Physikal. Kl., Fachgruppe 17 (Geologie und Mineralogie), Nr. 20, pp. 122–134, 1932.

[18] Gruner, J. W.: op. cit., p. 582.

TABLE IV.

HYDROTHERMAL EXPERIMENTS WITH LABRADORITE IN ACIDIC AND BASIC SOLUTIONS.

No.	Temp. ° C.	Time, hours	Grams NaCl	Grams SiO_2	Normality of solutions		Products	Remarks
					HCl	NaOH		
37	400	163	3.50			0.050	Sodalite and "A" (?)	Euhedral dodecahedrons
40	400	162	3.50		0.35		Pyrophyllite	
39	400	162	3.50	0.150		0.010	Labradorite (basic), quartz and "A" (?)	
42	400	162	3.50	0.150		0.050	Labradorite (acid), quartz and "A" (?)	
43	400	162	3.50	0.150		0.150	Oligoclase, albite, sodalite and "A" (?)	Albite as secondary growths
41	400	162	3.50	0.150	0.10		Labradorite (basic)	

sodium chloride content of the solution. This possibility did not exist in the experiments with albite since the potassium equivalent of the sodalite group of minerals is not known to exist. Microscopic examination of the powder showed that the labradorite had been completely destroyed, and only small, euhedral dodecahedrons of sodalite were visible.

Four experiments (Nos. 39, 41, 42, and 43) were made to determine the conditions under which albitization might occur. Albitization might take place according to equation (9),

$$CaAl_2Si_2O_8 + 4SiO_2 + 2NaCl \rightarrow 2NaAlSi_3O_8 + CaCl_2. \qquad (9)$$

In experiment No. 41 labradorite was treated at 400° C. in 0.10 N hydrochloric acid to which 150 mg of "silicic acid" had been added. The labradorite remained unaltered, and a microscopic examination showed the indices of refraction to be unchanged. Labradorite was also stable at 400° C. in a 0.010 N sodium hydroxide solution (experiment No. 39) to which 150 mg of "silicic acid" had been added. The indices of refraction of the labradorite were unchanged. A few acicular crystals which may be product "A" were observed microscopically. The X-ray powder diagram also showed, besides labradorite, the presence of quartz.

In more basic solutions, however, the expected reaction, or a comparable one, was obtained. When experiment No. 37, in which sodalite had been produced at 400° C. in 0.050 N sodium hydroxide, was repeated with the addition of 150 mg of "silicic acid" (experiment No. 42) some sodium substitution in the labradorite occurred, and no sodalite was formed. The X-ray powder diagram as a whole still corresponded with that of the original labradorite. A microscopic examination, however, showed that the indices of refraction had been very slightly lowered, and that they corresponded with those of labradorite containing more sodium. The excess silica was also recrystal-

lized to quartz in this experiment. A few acicular crystals which may be product "A" were observed microscopically. In experiment No. 43, in which the conditions were the same as in experiment No. 42 except that the solution was more basic (0.150 N), the albitization was very pronounced. The X-ray power diagram showed the resulting powder to consist of soda-rich plagioclase and sodalite. Microscopically it was found that the feldspar was not all the same composition. A few clear grains and rather abundant aggregates of minute grains had indices of refraction corresponding to medium oligoclase. Many slightly turbid grains showed secondary growths of clear feldspar. The indices of this clear material corresponded with those of albite. This albite was not optically continuous with the nucleus. The turbid nucleus possessed a very slightly higher index of refraction and may have been oligoclase.

The presence of sodalite in this experiment might suggest that the soda-rich plagioclase was beginning to alter to sodalite, but this is not believed to have been the case. In the other two experiments (Nos. 39 and 42) in basic solutions the unused "silicic acid" was crystallized to quartz. In experiment No. 43 no quartz resulted and a silica-deficient mineral was formed. Also, the plagioclase was not completely altered to albite. These facts all suggest that insufficient silica was present to permit the suggested reaction to proceed to completion. Calculations based on the assumption that equation (9) did govern the reaction show that 193 mg of "silicic acid" would have been necessary to alter all the labradorite to albite. It is noteworthy that the excess amorphous "silicic acid" in experiments Nos. 39 and 42 was crystallized to quartz in basic solutions, but not in acid ones (experiment No. 41).

The results are not entirely in agreement with those of Eskola, Vuorists and Rankama,[19] who stated that the extent of albitization is a function of the temperature and that only oligoclase or andesine could be obtained above 360° C. The present experiments indicate that the extent of albitization is a function of the pH of the solution, and that, under the proper conditions, soda feldspars rather than lime feldspars are the stable plagioclases at 400° C., and for an undetermined range both above and below that temperature.

CONCLUSIONS.

Hydrothermal experiments with albite and labradorite, mostly at 400° C., show that the plagioclase feldspars can be readily altered to some of the hydrothermal products occurring in nature. Potassium sulfide solutions yield the same results as do potassium hydroxide solutions.

Albite, when subjected to chloride solutions containing an excess of potassium ions at 400° C., is altered to one of three products, depending on the pH of the solution:

1. Albite alters to kaliophilite in potassium hydroxide solutions more basic than 0.05–0.07 N, and in potassium sulfide solutions more concentrated than about 0.08 M.

[19] Eskola, P., Vuorists, U., and Rankama, K., Experimental illustration of the spilite reaction: Comm. géol. Finlande, Bull. No. 119, pp. 61–69, 1937.

2. In potassium hydroxide solutions less basic than 0.05–0.07 N, in neutral solutions, and in hydrochloric acid solutions as acidic as 0.001 N albite alters to orthoclase by base exchange.
3. In solutions more acidic than about 0.001 N and less acidic than 0.020 N albite appears to be stable during the time of the experiment.
4. In hydrochloric acid solutions more acidic than 0.020 N albite partially alters to pyrophyllite.

LIBRARY JUN 7 194

Over the same range of conditions in which albite alters to orthoclase in the presence of excess potassium ions orthoclase and microcline can change to albite in the presence of an excess of sodium ions. However, Gruner has found [20] that the presence of alumina inhibits this base exchange, at least in neutral solutions.

If alumina is present in excess in a solution containing an excess of potassium ions albite is altered to muscovite in potassium hydroxide solutions as basic as 0.01 N. In more basic solutions kaliophilite is the stable alteration product.

Preliminary experiments indicate that basic plagioclase behaves similarly to albite. Pyrophyllite is formed in moderately acid solutions. In moderately basic solutions a product is formed which depends on the sodium salt present in the solution. Sodalite resulted when strong sodium chloride solutions were used, although a more dilute salt solution might have yielded nepheline or analcite.

Albitization of basic plagioclase occurs when silica and excess sodium ions (from sodium chloride) are present in sodium hydroxide solutions at least as basic as 0.050 N. The degree of albitization increases with increase in basicity up to 0.150 N, the most basic solution used. No albitization occurred under otherwise comparable conditions in 0.100 N hydrochloric acid nor in 0.010 N sodium hydroxide. In the latter two solutions the labradorite remained unaltered.

In experiments in which amorphous "silicic acid" was added to the system excess silica was crystallized to quartz in basic but not in acid solutions. Although basic solutions in other experiments sometimes contained 3,000 to 4,000 parts per million of silica as one of the reaction products, no quartz was formed because saturation had not been reached.

With the exception of the experiments in which only base exchange occurred, it is thought that the mineral which was unstable in the new environment passed into solution, and its ions were then rearranged to form stable products. The sodalite, kaliophilite, muscovite, and the feldspar crystals and accretions all have the appearance of having formed by precipitation from solution. Does the feldspar dissociate hydrolytically in the solution with resulting K^+ and Al^{+++} ions and SiO_4 groups? The degree of ionization should be extremely small in such a system. Despite the fact that the solution at a given instant might contain only a very small amount of the feldspar constituents the feldspar could dissociate as fast as the formation of the new stable compound removed ions from solution.

[20] Gruner, J. W.: op. cit., p. 582.

ACKNOWLEDGMENTS.

The helpful criticisms of Dr. John W. Gruner during the progress of the experimental work in his laboratory at the University of Minnesota and the preparation of the manuscript are gratefully acknowledged. Numerous discussions with Dr. R. B. Ellestad were very helpful.

AUSTINVILLE, VA.,
Jan. 22, 1948.

TUNGSTEN MINERALIZATION AT THE IMA MINE, BLUE WING DISTRICT, LEMHI COUNTY, IDAHO.*

ALFRED L. ANDERSON.

CONTENTS.

	PAGE
Abstract	181
Introduction	182
Geologic setting	184
General statement	184
Granite	184
Structural relations	184
Descriptive features	184
Mineral relationships	185
Paragenesis	188
Tungsten mineralization	188
Compositional features	188
Structural features	189
Wall-rock alteration	189
Mineralogy	190
General features	190
Descriptive features	190
Paragenesis	200
Zoning	202
Genesis	203
Role of the granite	203
Genetic history	203
Temperature and pressure	204
Age	205
Summary and conclusions	205
Acknowledgments	206

ABSTRACT.

The Ima mine, which has been one of the leading producers of tungsten in the United States, is of exceptional interest because of (1) the many different minerals contained in its ore, (2) the zonal arrangement of the minerals about a mass of granite exposed in underground workings, and (3) the close relationship between the mineralization and the formation of granite.

The mineralization is confined to a complex group of fractures along the crest of an anticlinal fold of quartzitic strata belonging to the Belt series (pre-Cambrian) near a small irregular mass of early Tertiary (?) granite. The fractures hold quartz veins, some near the granite being relatively large. Although composed mainly of quartz, the veins also contain microcline, fluorite, muscovite, sericite, rhodochrosite, siderite, and calcite, the microcline, muscovite, and fluorite occurring near the granite,

* Presented before the Society of Economic Geologists, Ottawa Meeting, Dec. 1947.

the sericite and rhodochrosite, generally more distant therefrom. The metal-bearing minerals are molybdenite, pyrite, sphalerite, tetrahedrite, chalcopyrite, galena, gratonite, scheelite, and huebnerite, the huebnerite, tetrahedrite, and pyrite being most abundant. The scheelite and molybdenite occur in and near the granite. The others have a less-restricted distribution, the huebnerite least of all. The huebnerite appears to be one of the youngest minerals. Microscopic features of the granite suggest that it formed at least in part by "granitization" of quartzite and that its formation may represent the initial stage of the mineralizing process.

INTRODUCTION.

THIS paper considers primarily the genetic aspects of the tungsten mineralization at the Ima, the sole operating mine in the Blue Wing district in southeastern Lemhi County, Idaho, and until recently one of the leading producers of tungsten in the United States. The mineralization displays some exceptionally interesting genetic features and is otherwise of interest because of the unusually large number of minerals and their difficultly decipherable relationships.

Umpleby [1] was first to describe the mineralization and comment on the large number of mineral species and their baffling relationships. Livingston [2] visited the district later, but he was mostly concerned with the details of occurrence and commercial possibilities of the deposits. In the summer of 1939 the writer, who spent 10 days in the district for the U. S. Geological Survey and the Idaho Bureau of Mines and Geology, became intrigued by the complex mineral relationships and the genetic aspects of the mineralization with reference to a previously undisclosed body of granite, but the report [3] that was prepared on the geology and mineralogy of the deposits was not published. The next year the district was visited by Callaghan and Lemmon on a Strategic Minerals Investigation for the U. S. Geological Survey and their report [4] includes a brief description of the minerals and their rough zonal arrangements about the body of granite. In 1942 the writer incorporated some of his findings in a general discussion of granite and ore.[5] Uncertain still of some of the mineralogic relationships, the writer returned to the district for a day in 1944 and obtained additional information on the mineralization, available as a result of the more extensive development. Since then the collections of ores and rocks obtained during both visits have been carefully studied with the ore and petrographic microscopes and the laboratory results integrated with the field observations.

This very interesting mineralized district is on the west slope of the Lemhi Range in T.14N., R.23E., Boise meridian, about 65 miles from Salmon, the county seat, and 56 miles by nearest road from Mackay, the shipping point and the terminus of a branch of the Union Pacific Railroad. The range is a tilted

[1] Umpleby, J. B., Geology and ore deposits of Lemhi County, Idaho: U. S. Geol. Survey Bull. 528, pp. 73–74, 77–79, 109–112, 1913.

[2] Livingston, D. C., Tungsten, cinnabar, manganese, molybdenum, and tin deposits of Idaho: Idaho Univ. Bull. 2, vol. 14, pp. 21–25, 1919.

[3] Anderson, A. L., Geology and mineralogy of the tungsten deposits in the Blue Wing district, Lemhi County, Idaho: U. S. Geol. Survey, Unpublished manuscript report.

[4] Callaghan, E., and Lemmon, D. W., Tungsten resources of the Blue Wing district, Lemhi County, Idaho: U. S. Geol. Survey Bull. 931–A, pp. 1–21, 1942.

[5] Anderson, A. L., Granite and ore: ECON. GEOL., vol. 37, pp. 514–517, 1942.

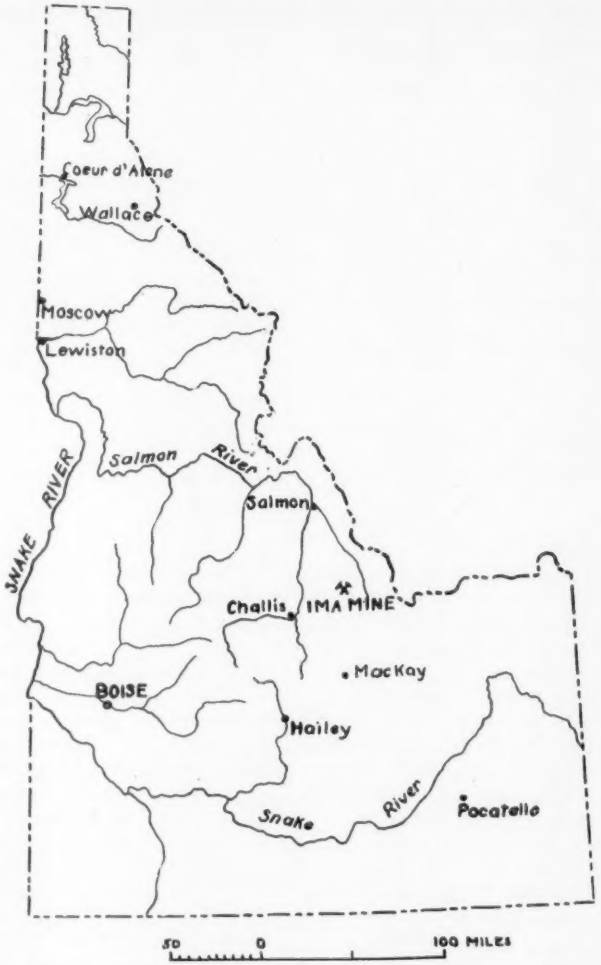


FIG. 1. Index map showing location of the Ima mine, Idaho.

block of northwesterly trend and great linear extent, bordered by and rising high above broad basins of the desert type,[6] locally as much as 5,000 feet above Pahsimeroi Valley at its west base. The mine is on the rugged north canyon wall of Patterson Creek about a mile above the settlement of Patterson, which

[6] Anderson, A. L., Drainage diversion in the Northern Rocky Mountains of east-central Idaho: Jour. Geology, vol. 50, pp. 63–67, 1947.

is located at the mouth of the canyon. The location of the mine within the State is shown in Fig. 1.

GEOLOGIC SETTING.

General Statement.

The tungsten mineralization is centered about an irregular mass of granite exposed in the underground workings at the Ima mine and is confined to fractures along the crest of a prominent anticlinal fold of quartzitic strata belonging to the Belt series (pre-Cambrian). The fold, which is crossed by the deep, narrow canyon of Patterson Creek, forms a broad arch reaching from the mouth of the canyon to the forks of the stream about 2 miles above. The concealed body of granite is near the center of the fold and the principal fractures are in the strata above. The fracturing is complex and most of the fractures and fracture zones trend N.30°–40°W. about parallel to the axis of the arched strata.

As the granite is the only rock that is directly involved in the mineralization, aside from the quartzitic host, it is the only one that will be given extended treatment. Except for the fractures in them, which have localized mineral deposition, the quartzites have no features pertinent to the present study.

Granite.

Structural Relations.—As exposed far back on the intermediate and lower levels of the mine, the granite mass is most irregular, being aligned along and split and broken by numerous faults (Fig. 2). It appears to be in the most extensively fractured part of the anticlinal structure and its irregularity apparently, in part at least, has resulted from the direction of pronglike off-shoots along fractures which trend somewhat west of north. The body appears to enlarge with depth and to plunge southeast beneath the mine. Between the intermediate and lower levels, its dip is about 30°S., but beneath the lower level, the dip, as indicated by diamond drilling, flattens to about 18°S.

Descriptive Features.—Much of the granite is moderately coarse-grained and distinctly granular, but locally at margins it is finer and distinctly aplitic. Some of the finer-grained rock is also somewhat porphyritic, and, as the phenocrysts become more numerous inward, the rock grades into the granular, more coarsely crystalline facies. The contact of the granite with the quartzite generally appears to be sharp, but actually it is abruptly gradational, and the granite merges with the bordering, locally biotite-enriched quartzite.

The granite is pinkish and consists largely of pinkish microcline and orthoclase with abundant quartz, some altered plagioclase, and a little muscovite or altered biotite. The proportions of these minerals in the moderately coarse-grained rock average about 25 per cent quartz, 20 per cent orthoclase, 30 per cent microcline, 20 per cent altered plagioclase, 5 per cent muscovite, and less than 1 per cent of each of the accessories, apatite and zircon. The finer-grained rock contains less plagioclase and orthoclase and proportionately more microcline. The plagioclase grains in all the rocks are chalky white and have

been almost completely replaced by aggregates of coarse sericite. The pinkish orthoclase and microcline grains are surprisingly little altered, if at all.

All the granite so far revealed in the mine workings contains quartz veinlets and disseminated sulfides and fluorite. Surfaces of the much fractured

LIBRARY
JUN 7 1948

FIG. 2. Map showing veins and granite on the lower level of the Ima mine (adapted from U. S. Geol. Survey Bull. 931, Pl. 2).

granite are commonly coated by muscovite or molybdenite, some by both, and many fractures have thin seams of pyrite.

Mineral Relationships.—Although superficially the granite appears to be like any normal granite, the relations of the minerals are not those ordinarily ascribed to magmatic crystallization. Instead of interlocked euhedral, sub-

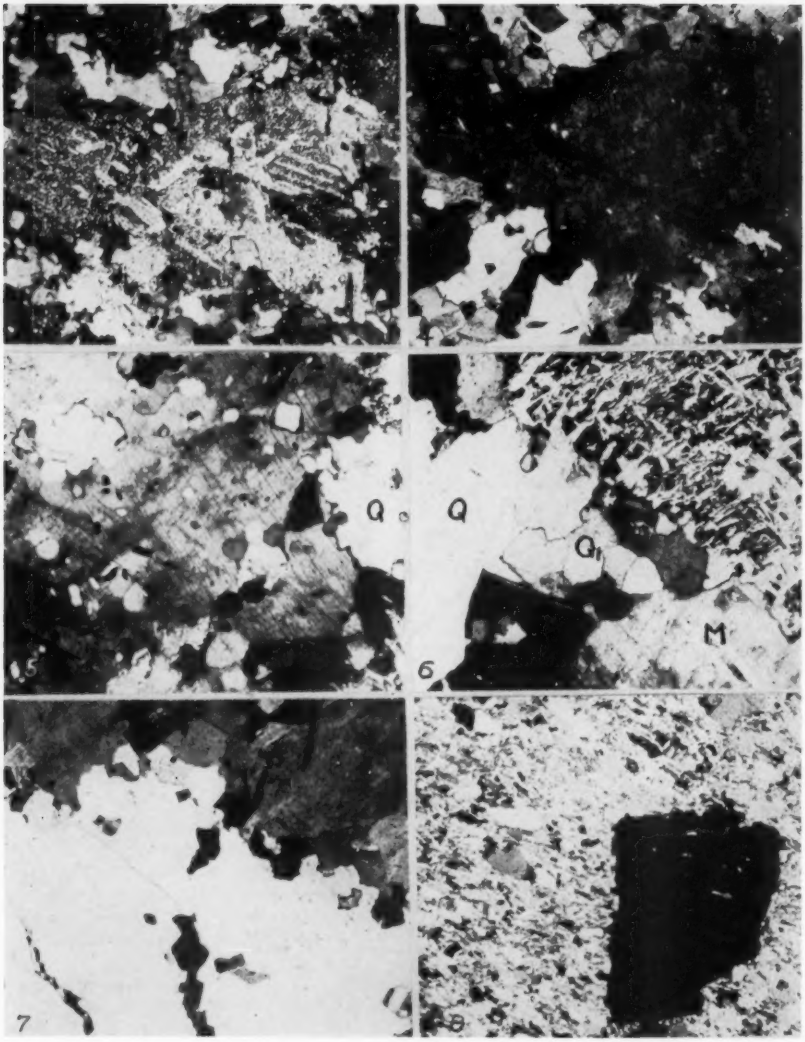


FIG. 3. Partly sericitized sodic plagioclase (multiple twinning) developed in a quartzitic matrix which has been invaded by interlacing grains and veinlets of microcline. The microcline grains penetrate and cause irregular borders on the plagioclase crystals. Crossed nicols. × 35.

FIG. 4. Microcline crystal (dark gray) impregnating quartzite. Borders of the crystal are uneven and have protuberances which penetrate the quartzitic matrix. Small grains of microcline have been added to the matrix. Crossed nicols. × 35.

hedral, and anhedral grains, the rock contains grains which are embayed and penetrated by adjoining grains and grains which contain irregular remnant inclusions of other grains. Among the included grains are mosaics of interlocking quartz grains like those of the adjacent quartzite.

Microscopic study of the aplitic and somewhat porphyritic marginal rock discloses about as much quartzitic material as granitic and indicates that it is actually quartzite that has been impregnated by feldspar and mica (Figs. 3, 4, 5, 6). The matrix of the rock is composed of small, granular, more or less equidimensional, interlocking quartz grains like those of the quartzite, but it may also contain interlacing small grains and irregular veinlets of microcline. Occurring as scattered phenocrysts in this quartzitic matrix are seemingly well-shaped but actually irregularly bordered crystals of highly altered andesine (Fig. 3), commonly with quartz inclusions, and also irregularly bordered crystals of orthoclase and microcline with protuberances that penetrate into the quartz mosaics (Fig. 4). The matrix also contains grains of muscovite which appear to be pseudomorphous after biotite and which have protuberances that penetrate the adjoining minerals as though in added growth. As the feldspars and particularly the orthoclase and microcline increase in abundance in from the margin, the quartzose matrix tends to disappear, but the feldspars continue to hold remnant quartz inclusions (Fig. 5). Even in the granite well within the body, patches of mosaic quartz may remain between the feldspar grains (Fig. 6) and occur as remnant inclusions within.

There are also embaying and penetrating relationships among the feldspars. The plagioclase penetrates only the quartzitic matrix, but the orthoclase and microcline also embay irregularly into the plagioclase grains (Fig. 6) and may extend even through them with retention of detached, oriented remnants as inclusions. Apparently considerable plagioclase has been lost as a result of replacement by the potash feldspars. In the same way that the potash feldspars embay and penetrate plagioclase, so does the microcline embay and penetrate the orthoclase and retain in it remnants of the orthoclase as engulfed inclusions.

The most striking embayments, however, are those made by large grains of lobate quartz, which constitute the bulk of the quartz in the granite. These grains penetrate and embay irregularly into all the feldspars and even penetrate the granular quartz mosaics (Fig. 6), commonly retaining remnants of these minerals as oriented inclusions (Fig. 7).

FIG. 5. Large grain of microcline with numerous remnant inclusions of the quartzite. The microcline is embayed by a grain of lobate quartz (Q). Crossed nicols. × 35.

FIG. 6. Thoroughly granitized rock but still retaining a remnant of the quartzite (Q_1). The plagioclase showing the typical coarse sericitic alteration is unevenly bordered and partly penetrated by microcline (M) and by young quartz (Q). Crossed nicols. × 35.

FIG. 7. Feldspathized rock invaded by a large grain of lobate quartz (white) which penetrates unevenly into bordering feldspar grains and retains remnants of them as irregular inclusions. Crossed nicols. × 35.

FIG. 8. Sericitized quartzitic wall rock at vein border. Shows penetration of quartz by sericite along fractures and grain borders and replacement of the sericitized rock by pyrite (black), which retains sericite inclusions. Crossed nicols. × 35.

The remaining minerals of particular interest are the muscovite and coarse sericite, some of which appear to be pseudomorphous after original biotite but most of which form coarse grained aggregates pseudomorphous after plagioclase (Fig. 6). Much of the plagioclase may be recognized only by the coarse sericitic aggregates through which the polysynthetic twinning is generally scarcely discernible. The potash feldspars on the other hand show no sericite or muscovite.

The accessory apatite and zircon in the rock form occasional small grains along cleavages and grain boundaries of the other minerals and possibly along fractures.

The fluorite and pyrite grains that impregnate the granite; the seams and veinlets of quartz, micas, and pyrite that cut it; and the molybdenite and mica that coat fracture surfaces are closely associated with or are a part of the subsequent mineralization to be dealt with later.

Paragenesis.—The mineral relationships indicate that the granite is simply quartzite impregnated and largely replaced by feldspar and quartz. The first mineral to form in the quartzite was biotite, some of which remains untouched in the quartzite bordering the granite. Much of the biotite in the "granitized" quartzite, however, was destroyed by the feldspars, which replaced it, and by the muscovite into which the remaining grains were changed. By successive replacements, sodic plagioclase, orthoclase, and microcline were added, and lastly quartz and accessories. The succession is depicted diagrammatically in Table 1, which shows the ore succession in full.

TUNGSTEN MINERALIZATION.

Compositional Features.

The tungsten association is primarily a quartz-tungsten association with huebnerite in fracture-controlled quartz veins. Close to the granite, however, the veins also contain appreciable quantities of silver, lead, copper, and zinc, which are recovered, and molybdenum, which is not saved. On the presence or absence of sulfides the veins may be classed (1) as complex silver-tungsten veins and (2) as simple tungsten veins. The entire production to date has come from the complex veins within a few hundred feet of the granite.

The tungsten and base metals constitute only a small part of the vein filling. About 95 per cent of the ore sent to the mill is composed of gangue minerals of which at least 90 per cent is quartz. In the quartz-tungsten veins the quartz makes up fully 99 per cent of the filling. The ore that is milled averages about 0.72 per cent huebnerite, about 4 per cent sulfides, and 1.75 ounces of silver per ton. The tungsten concentrate that is produced averages 67 per cent WO_3 and the sulfide concentrate, about 42 ounces of silver and 0.01 ounce of gold per ton, 3.75 per cent copper, 7 per cent lead, 5 per cent zinc, 28 per cent iron, 1 per cent lime, 0.5 per cent WO_3, and 12 per cent insolubles.[7] The molybdenum occurs in variable quantities in and near the granite, being highest in the granite, but constitutes about 0.08 per cent of the ore that is mined.

[7] Callaghan, E., and Lemmon, D. W., U. S. Geol. Survey Bull. 931–A, op. cit., p. 6.

Structural Features.

The veins follow the fracture zone at the crest of the anticlinal arch and extend downward through the sedimentary rocks into the granite. Most of the veins are small and lenticular and rarely exceed 100 feet in length and 2 feet in thickness, but a few close to the granite are relatively large. Among the large veins are the productive veins at the Ima mine. At greater distances from the granite the veins though more numerous are much smaller, less continuous, and less promising.

The main vein at the Ima, which has been exposed underground for 1,700 feet, penetrates the granite; but before reaching the granite it splits into three branches, each of which diminishes in size as it extends inward from the granite contact (Fig. 2). The vein and its branches pinch and swell abruptly on strike and dip, and locally the swells reach a maximum thickness of 35 feet. The richer ore is contained in the wider parts of the veins, and the valuable ore shoots terminate at or near the granite contact.

The veins generally have well-defined walls suggestive of fissure filling, but some of the larger veins in the quartzite have walls that are rather indefinite and show transitional contacts. Such veins usually contain considerable brecciated quartzite whose fragments are barely perceptible as shadow-like inclusions.

Wall-rock Alteration

Alteration of the wall rock is one of the pertinent features associated with the tungsten mineralization. The quartzite is the chief rock involved, but the granite also has been altered, even more intensely than the quartzite. The quartzitic wall rock generally shows variable but considerable alteration depending largely on the distance from the granite. The alteration is more evident about the larger, complex veins near the granite than about the smaller, simple veins some distance away, and may be scarcely noticed at all about those near the margin of the district. Where altered, the rock appears somewhat bleached and has a light gray to pale greenish color; but as the rock is naturally rather light in color, the bleaching does not stand out conspicuously even where the alteration has been relatively intense. Locally the alteration has been accentuated by a faintly to strongly developed schistosity parallel to vein borders and by the presence of small, widely disseminated crystals of pyrite.

The alteration is chiefly sericitic, and examination of thin sections shows that the wall rock has been more or less extensively replaced by sericite (Fig. 8) and very subordinately by pyrite and fluorite. The sericite is generally most abundant immediately adjacent to the veins and in places has replaced the rock almost completely, changing it to a schistose quartzite and sericite schist; but in other places, even along the same veins, the sericite may be more sparingly developed and the rock may remain as essentially massive, partly sericitized quartzite. The sericite has replaced the quartz along minute shear fractures and along grain borders. Elongation of the grains parallel to the shearing has given rise to the local wall schistosity. Much of the sericite is relatively fine-grained, but some nearest the vein and in wall-rock fragments in the vein is relatively coarse and becomes coarser still near the granite.

The sericitized quartzite is in turn impregnated by small, disseminated cubes of pyrite, which replace the quartz grains as well as the sericite grains (Fig. 8), and by scattered minute grains of fluorite. Much of the pyrite measures about one sixteenth of an inch square but increases to one half inch or more near the granite.

The granite has been similarly but in general more intensely altered than the quartzite. Because the potash feldspars resisted and largely escaped alteration, the rock looks fresh; but most of the plagioclase has been changed completely to coarse sericitic aggregates (Fig. 6) and the biotite, to muscovite. The sericitized rock has in turn been impregnated by scattered crystals of pyrite and by rather numerous grains of fluorite. In addition there are the seams and veinlets of quartz, micas, and pyrite that cut the granite and the molybdenite and mica that coat fracture surfaces, but these are features associated more directly with the metallization rather than with the wall-rock alteration.

The dominant process of alteration thus has been sericitization, supplemented subordinately by pyritization. The addition of fluorite is probably a local effect, confined to the wall rock enclosing the main ore bodies and to the granite. The sericitization and pyritization, pronounced near the granite, extend outward in more feeble form. The sericitized rock along the main ore bodies apparently has supplied the coarse sericite found closely associated with much of the sulfide ore.

Mineralogy.

General Features.—The complex silver-tungsten veins are somewhat exceptional because of the large number of elements and the still larger number of minerals they contain. In addition to the quartz already mentioned, the veins contain varying amounts of fluorite, rhodochrosite, muscovite, sericite, microcline, siderite, and calcite as associated gangue minerals. In addition to the huebnerite, they contain pyrite, tetrahedrite, chalcopyrite, galena, sphalerite, molybdenite, gratonite ($9PbS.2As_2S_3$), and scheelite as the associated metal-bearing minerals. Bornite has been reported [8] but was not seen by the writer.

Secondary minerals include anglesite and pyromorphite after galena, azurite and malachite after chalcopyrite and tetrahedrite, covellite and chalcocite after galena and chalcopyrite, tungstite after huebnerite, erthyrite after some unknown primary cobalt mineral, molybdite after molybdenite, and various manganese oxides after rhodochrosite and huebnerite. Because these minerals are present in trivial quantities and have no pertinent bearing on the tungsten mineralization, they will not be considered further.

Descriptive Features.—The primary minerals are present in variable amounts and show a variable distribution. Such minerals as tetrahedrite, huebnerite, pyrite, molybdenite, fluorite, mica, and rhodochrosite are locally fairly abundant, but the others, except for the ever-predominant quartz are present in scant though variable quantities. The quartz and huebnerite are

[8] Callaghan, E., and Lemmon, D. W., U. S. Geol. Survey Bull. 931–A, op. cit., p. 10.

distributed through all the veins and form the chief filling of most. The others are restricted more or less closely to the vicinity of the granite.

In places the sulfides and huebnerite have a rude, banded arrrangement; but generally they are distributed at random through the quartz, the sulfides as granules and small irregular masses, the huebnerite as scattered crystals. Because of the absence of continuous sulfide bands and large sulfide masses, the veins have a coarse "salt and pepper" structure, the sulfides and huebnerite appearing as though sprinkled irregularly through the quartz. Much of the filling in the complex silver-tungsten veins, however, has a faintly mottled or breccia-like appearance, apparently because of phantom inclusions of the altered country rock.

Quartz in the veins is mostly white and rather coarsely crystalline. That near the granite is quite massive and is composed of coarse, interlocking crystals, which in places are somewhat loosely united permitting small open clefts. That in the veins more distant from the granite tends to be less massive with more open spaces and in part to possess a poorly developed comb habit. Accompanying the sulfides near the granite, however, is a somewhat grayish and more finely crystalline quartz, commonly with much sericite, which appears in the more coarsely crystalline variety as indistinctly brecciated, phantom inclusions. Except in thin section (Figs. 9, 10), this finer-grained quartz is not easily distinguished, although when its habit is known, it may be recognized by its sulfide association and the somewhat mottled appearance it gives to the quartzose vein fillings.

Study of thin sections reveals that the finer-grained quartz is composed of interlocking aggregates (Fig. 9) and that the quartz aggregates are more or less extensively sericitized (Figs. 9, 10) and are indistinguishable from the sericitized quartzitic wall rock (Fig. 8). The finer-grained quartz apparently has been inherited from the wall rock, and, as shown in Fig. 9, is contained as irregular fragmented inclusions in the coarsely crystalline vein quartz, and, as shown in Fig. 10, is penetrated and replaced by the coarsely crystalline quartz. The presence of the fine-grained quartz is significant, for the sulfides occur with and replace it, and to lesser extent the sericite; and together they are all strewn as irregular and unevenly penetrated and replaced fragments through the filling of younger, much more abundant quartz. Such minerals as fluorite and rhodochrosite also are scattered irregularly and sporadically as large grains and granular aggregates through the quartz. The huebnerite, in contrast with the sulfides, does not depend on the fine-grained quartz for its distribution, but it occurs with and is intimately associated with the coarsely crystalline quartz. Locally, however, as shown in Fig. 11, its crystals, like those of the coarse-grained quartz, penetrate into and replace or partly replace the fine-grained, sericitized quartz.

Huebnerite, unlike most of the other minerals, is not restricted to the vicinity of the granite, but is as widely distributed as the white, coarsely crystalline quartz. It is a sparsely distributed mineral, occurring as scattered, reddish-brown prismatic crystals, mostly in the white quartz. These crystals are commonly less than a half inch long but may range up to an inch and locally up to three inches. Some of the largest crystals were observed in the narrow

LIBRARY JUN 7

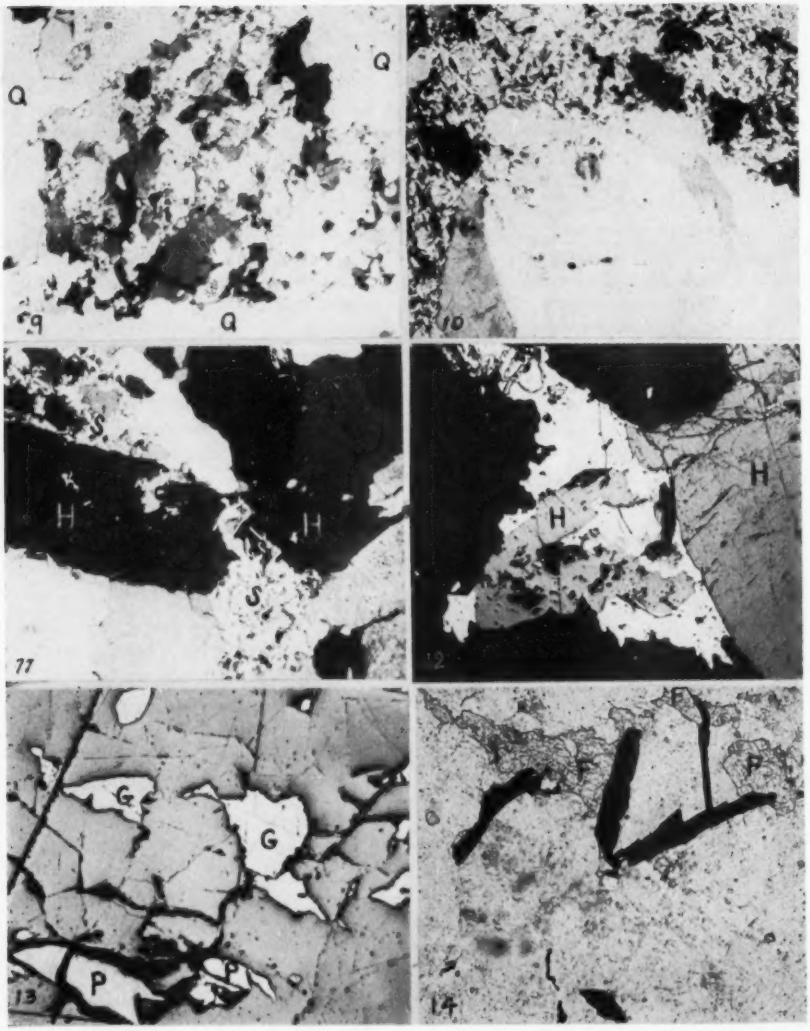


FIG. 9. Remnant of the somewhat sericitized quartzite engulfed in, penetrated, and partly replaced by the coarse-grained quartz (Q) belonging to the tungsten stage of deposition. × 35.

FIG. 10. Large crystal of young quartz penetrating and replacing thoroughly sericitized quartzite with retention of remnant sericite. × 35.

quartz veins remote from the granite. Huebnerite of a different character also occurs in fractures in the quartz. This second huebnerite is finely crystalline, soft, and easily powdered.

Analyses of the huebnerite [9] shows that it contains about 76.3 per cent tungstic trioxide, 21.5 per cent manganese oxide, and 2.2 per cent ferrous oxide.

The relations of the huebnerite to the coarse, granular quartz, which in places has a drusy habit, show that it was deposited rather early with quartz but that the quartz did not complete its crystallization until later. As a result the huebnerite occurs within and not upon the quartz crystals. Both the huebnerite and its associated quartz have entered extensively into and have replaced the earlier quartz (Fig. 11). The huebnerite also penetrates the sulfides (Fig. 12). In such cases its crystals may extend entirely through and may retain remnant sulfide inclusions (Fig. 13). To lesser extent, the huebnerite crystals penetrate and replace fluorite (Fig. 14) and rhodochrosite. In these and other replacements the huebnerite always develops its own crystal form.

As there is such a close association between the coarse huebnerite crystals and the coarse-grained quartz (see also Figs. 23, 24), they must be contemporaneous but with the quartz outlasting the huebnerite. The finely crystalline huebnerite, which occurs in fractures in quartz and other minerals (Figs. 15, 16), must be of a younger generation.

Microcline occurs as fairly conspicuous flesh-colored grains and masses in the veins near the granite and as seams in the granite. That in the veins forms irregular but in part rounded, coarse grains and finely granular masses engulfed in the quartz. That in seams in the granite forms coarse to finely granular aggregates which locally are penetrated and replaced by grains of mica and molybdenite.

Muscovite is found only in and near the granite, as seams which cut the granite and as micaceous aggregates within the quartz. The seams ordinarily are from one quarter to an inch thick, but some of the aggregates in the quartz are several inches thick. None of the seams is very persistent and those in the quartz form isolated, detached inclusions.

The crystals which make up the micaceous seams and aggregates are commonly as much as an inch in diameter; but outward from the granite the seams and bunches become smaller and less numerous and the muscovite becomes more finely crystalline, even sericitic. In some of the seams the muscovite is

[9] Shannon, E. V., The minerals of Idaho: U. S. Nat. Mus. Bull. 131, p. 468, 1926.

FIG. 11. Crystal of huebnerite (H) penetrating and replacing incompletely a remnant of sericitized quartzite (S), engulfed in the young coarsely crystalline quartz. × 35.

FIG. 12. A large crystal of huebnerite (H) slicing across a small body of galena (white), which is also penetrated and replaced by smaller euhedral crystals of huebnerite. × 90.

FIG. 13. A single crystal of huebnerite with remnant inclusions of pyrite (P) and galena (G). × 90.

FIG. 14. Crystals of huebnerite (black) which extend into and penetrate grains of fluorite (F). × 35.

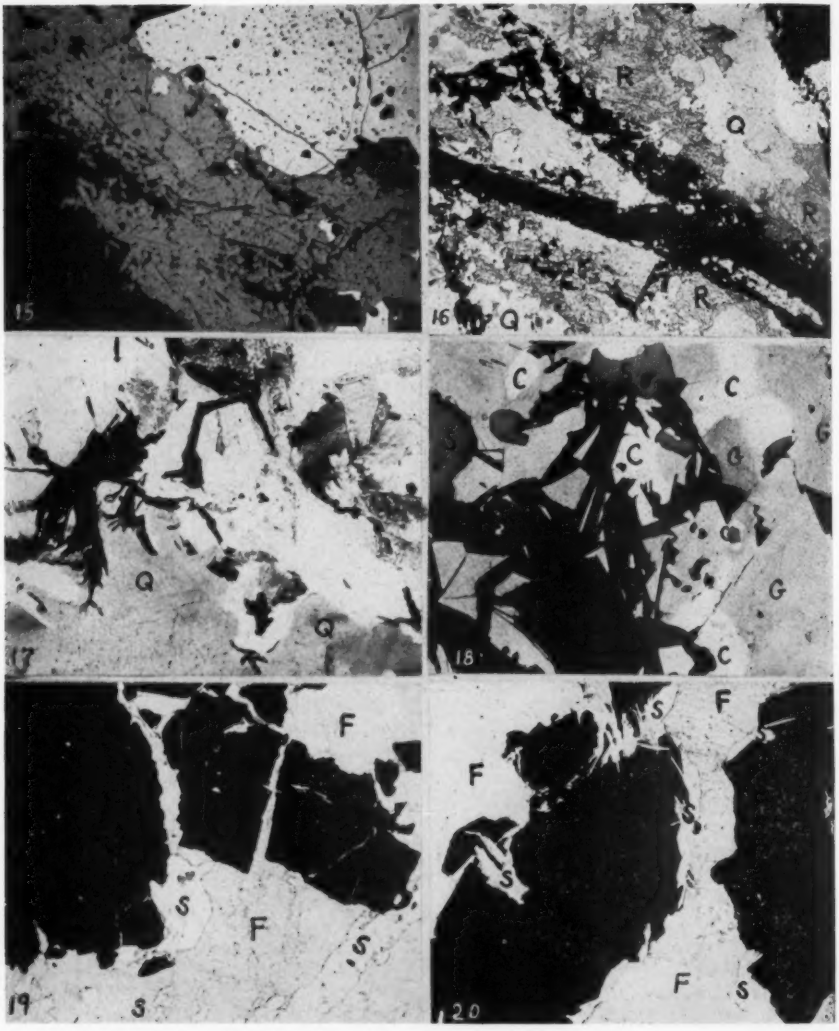


FIG. 15. Veinlet of finely crystalline, second-generation huebnerite (dark gray) cutting quartz (black) and tetrahedrite (light gray). The tungsten-stage quartz has impressed its automorphic form against the tetrahedrite whereas the huebnerite has impressed its crystal form against both tetrahedrite and quartz. × 90.

FIG. 16. Second-generation huebnerite (black) in fractures cutting rhodochrosite (R) and quartz (Q). × 38.

accompanied by molybdenite, and, as shown in Fig. 17, is penetrated and replaced by the molybdenite along grain boundaries and cleavages. Locally fluorite grains penetrate the muscovite seams and aggregates. The muscovite aggregates within the quartz apparently are engulfed inclusions, for, as shown in Fig. 17, the muscovite is penetrated and replaced by large grains of quartz.

Sericite, as mentioned earlier, is abundant in the granite as a secondary product after plagioclase and also in the quartzite as a product of wall-rock alteration. In addition it occurs as one of the less abundant gangue minerals in the sulfide-bearing veins, associated mainly with the fine-grained, aggregate quartz (Figs. 9, 10, 11) and with the sulfides (Fig. 18), usually as well-shaped, little-replaced grains. The sericite is also penetrated and replaced by huebnerite (Fig. 11). In some cases penetration of the aggregate sericite makes the huebnerite appear as though encased by sericite. Some sericitic aggregates are engulfed in fluorite and are rounded and corroded by it (Fig. 19).

Fluorite, among the gangue minerals, is next to quartz in abundance, but is prominent only in a zone extending about 600 feet from the granite contact. It is mostly greenish and purple in color and forms coarse grains and aggregates in the quartz, and locally in the bordering walls. Its distribution is sporadic, the grains and aggregates decreasing in size and abundance with increasing distance from the granite.

Fluorite which impregnates the walls replaces the sericitized quartzite and any sulfides that may be in it. It also impregnates the sulfide grains and aggregates within the veins, filling fractures in the sulfides (Fig. 19) or enveloping the grains and holding them as inclusions (Fig. 20). Some replacement of sulfides may take place, but the fluorite generally retains few, if any remnant inclusions. In penetrating the sulfides it also penetrates and replaces the accompanying sericite (Fig. 20) and may hold remnants of the sericite as somewhat rounded masses (Fig. 19). The fluorite is occasionally penetrated by huebnerite (Fig. 14). Although engulfed in the quartz, the fluorite is generally only slightly replaced (Figs. 21, 22). Some of the fluorite aggregates cut across and locally engulf small masses of rhodochrosite, impressing their own crystal form against rhodochrosite.

Rhodochrosite is not quite so abundant as the fluorite, but it extends out from the granite for a greater distance and is generally less abundant near the granite than at a distance. It forms small granules, bunches, and discontinuous or interrupted seams or veinlets in the coarsely granular quartz, and appears to be caught up in the quartz in much the same way as are the fluorite and sulfides. It commonly preserves its crystal outline against the quartz,

FIG. 17. Grains of molybdenite (black) penetrating muscovite aggregates along grain boundaries and cleavages. Aggregate invaded by large grain of the vein quartz (Q). × 38.

FIG. 18. Coarse sericite grains (black) in sulfides. Sericite is a constituent of all sulfide admixtures. Sulfides present are sphalerite (S), chalcopyrite (C), and galena (G). × 90.

FIG. 19. Fractured pyrite crystals (black) cemented by fluorite (F). The fluorite contains corroded remnants of sericite (S). × 38.

FIG. 20. Sphalerite (dark gray) and sericite (S) engulfed in fluorite (F). Only the sericite shows evidence of replacement. × 38.

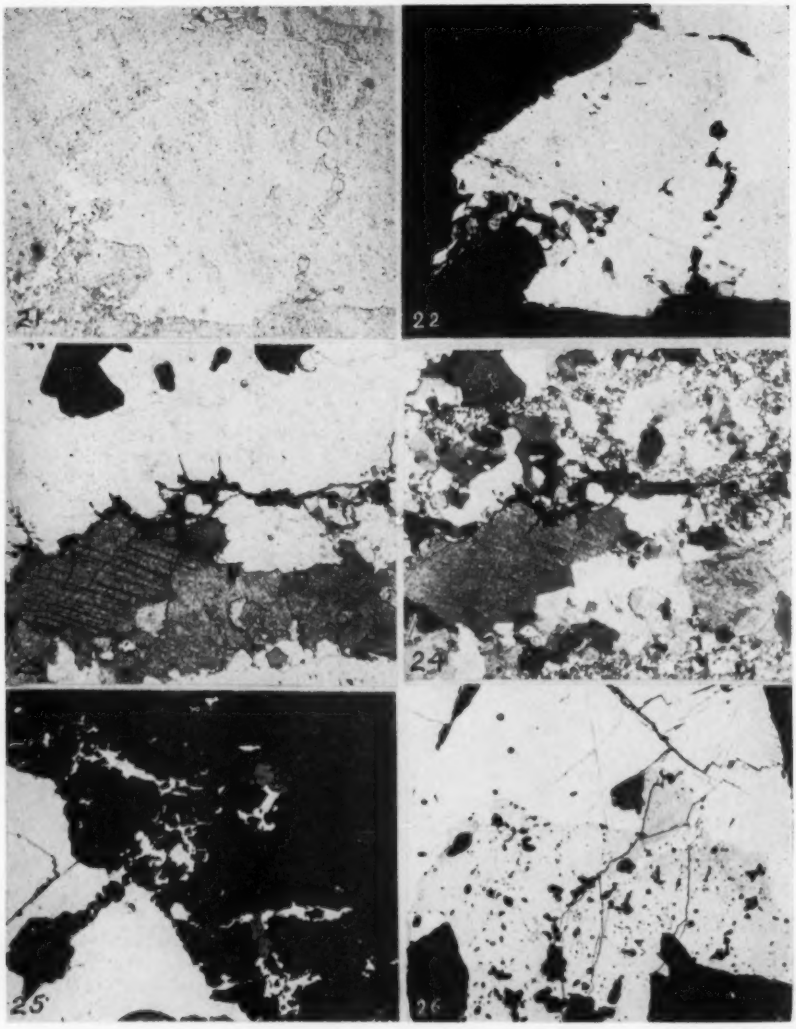


FIG. 21. Fluorite (gray) penetrated and partly replaced by a large crystal of tungsten-stage quartz, which retains irregular remnants of the fluorite. Uncrossed nicols. × 35.

FIG. 22. Same as Fig. 21 but with crossed nicols. Photomicrograph now shows a partly replaced remnant of fine-grained granular quartz which has been penetrated and partly replaced by the fluorite. × 35.

but it is occasionally penetrated by crystals of huebnerite. On the other hand its veinlets and crystals penetrate and replace the sulfides and sericitized quartz (Figs. 23, 24), commonly with retention of remnant inclusions (Fig. 25). In replacing the sulfides and quartz the rhodochrosite shows a marked tendency to develop its own crystal form (Fig. 26).

Tetrahedrite is the most abundant and most valuable ore mineral after huebnerite and occurs as irregularly disseminated grains and small masses closely associated with pyrite and other sulfides (except molybdenite). These minerals are persistently though not uniformly sprinkled through the quartz as irregular granules and small irregular bunches for at least 2,000 feet from the granite. The tetrahedrite is chiefly valuable because it contains 1.9 per cent silver.[10]

In common with the other sulfides the tetrahedrite is associated with and replaces the fine-grained quartz and retains and is admixed with coarse grains of sericite (Fig. 18). It is also penetrated and replaced by huebnerite (Fig. 15), by fluorite, by rhodochrosite (Fig. 26), and to a limited extent by the engulfing coarse-grained quartz. It holds as inclusions and corrodes any pyrite with which it may be in contact, and locally engulfs and cements fractured sphalerite. It may also hold small elliptical bodies of chalcopyrite and send small lobes and occasionally small veinlets into larger masses. But tetrahedrite-chalcopyrite boundaries seem for the most part to be mutual. It also appears to share mutual boundaries with much of the galena; but, in part, the tetrahedrite occurs as more or less-rounded blebs (Fig. 27) and as irregularly shaped inclusions (Fig. 28) in the galena and, in places, is partly penetrated and veined by galena (Fig. 26).

Pyrite is one of the more abundant metallic minerals; and, because of its presence in the granite and altered wall rock as well as in the veins, it is probably the most widely distributed. It has a cubic habit, but crystals associated with other sulfides are rounded (Fig. 29) or irregularly indented. The crystals in the veins and bordering walls are generally small, but they increase in size near the granite so that some measure up to two inches square.

The pyrite replaces the sericitized quartzite (Fig. 8), but some of the largest crystals are impregnations of muscovite seams and aggregates in and near the granite. It forms included, often corroded and remnant grains in

[10] Umpleby, J. B., U. S. Geol. Survey Bull. 528, op. cit., p. 111.

FIG. 23. Irregular sulfide veinlet (black) cut and replaced by a seam of rhodochrosite (gray). Huebnerite crystals (black) at the upper edge of the photomicrograph. Uncrossed nicols. × 35.

FIG. 24. Same as Fig. 23 but with crossed nicols. Shows that the irregular sulfide veinlet cuts and replaces sericitized quartzite and that the huebnerite crystals occur with the coarsely crystalline quartz. × 35.

FIG. 25. Galena (white) invaded and replaced by veinlet of rhodochrosite (dark gray) which retains irregular remnant inclusions of the galena and some also of sphalerite (medium gray). Veinlets along galena cleavages also are composed of rhodochrosite. × 90.

FIG. 26. In replacing tetrahedrite (gray) and galena (white) the rhodochrosite (black) in lower part of photomicrograph has taken its own crystal form. A veinlet of galena penetrates the tetrahedrite. × 90.

associated sulfides (Figs. 28, 29) and also remnant grains in huebnerite (Fig. 13). Locally, fractured pyrite is cemented by fluorite (Fig. 19). Near the granite some of the smaller pyrite grains are engulfed and the larger ones, penetrated and partly replaced by molybdenite.

Sphalerite is as widely distributed as the other sulfides but is not so abundant as the tetrahedrite and galena. Its grains are small, brownish in color, and are easily confused with some of the smaller huebnerite crystals in sulfide aggregates.

The sphalerite crystals are somewhat ovoid and are generally enveloped by tetrahedrite and galena (Figs. 18, and Figs. 27, 28, 29). Some grains are penetrated along fractures by tetrahedrite and chalcopyrite. Except for remnants of pyrite and sericite, the sphalerite is generally without inclusions.

Chalcopyrite is one of the lesser sulfides, and, except in polished sections, is rarely visible to the eye. It is widely thought sparingly distributed and has been found with the molybdenite in or near the granite as well as with the tetrahedrite and galena up to 2,000 feet distant.

The chalcopyrite has been observed as a filling of fractures in pyrite and sphalerite and as larger, generally rounded grains in tetrahedrite and galena (Fig. 30). Some of the larger grains seem to have mutual boundaries with tetrahedrite and galena. The relations of the chalcopyrite associated with the molybdenite were not determined.

Galena is as widely distributed but is not so abundant as the tetrahedrite and therefore is not conspicuous in the ore. Some of its grains are large enough to hold other sulfides as inclusions, but in general its grains are smaller than those of the tetrahedrite. Fine-grained aggregates as much as a half inch thick and an inch or two long are exceptional. With the other sulfides it occurs as small, irregular granules and small masses scattered through the quartz.

Most of the relations of the galena have already been noted, particularly the tendency of its larger grains to hold corroded remnants of pyrite and sphalerite as inclusions (Fig. 29) and for veinlets to penetrate and apparently replace tetrahedrite (Fig. 26) and to encase chalcopyrite (Fig. 30). Mention has also been made of the way it may be penetrated and replaced by crystals of huebnerite (Figs. 12, 13) and rhodochrosite (Figs. 25, 26).

Gratonite ($9PbS.2As_2S_3$) was found in a single hand specimen as microscopic grains in chalcopyrite and galena (Fig. 30). It forms white rhombic crystals of about the same hardness as galena but is easily distinguished from the galena by its strong anisotrophism and its prominent yellow and blue polarization colors. It is negative to all the ordinary etch reagents, except nitric acid, with which there is abundant effervescence, and iridescent to black staining. It gives microchemical tests for lead, arsenic, and sulphur.

Some of the rhombic crystals of gratonite contain irregular inclusions of galena and chalcopyrite, evidently as remnants of replacement. The gratonite develops its own euhedral form in these replacements.

Molybdenite is more restricted in its distribution than most of the other minerals and is found only in and near the borders of the granite. From the granite outward it becomes less plentiful, especially laterally, but appears to

extend above the granite for greater distances and in somewhat greater quantity.

The molybdenite in the granite is both disseminated and in fractures, either as thin coats on fracture surfaces or as irregular aggregates in micaceous seams. That in the veins forms thin pods and foliated masses, commonly with muscovite or sericite, and thin sheets along fractures which cut the vein filling and the bordering walls.

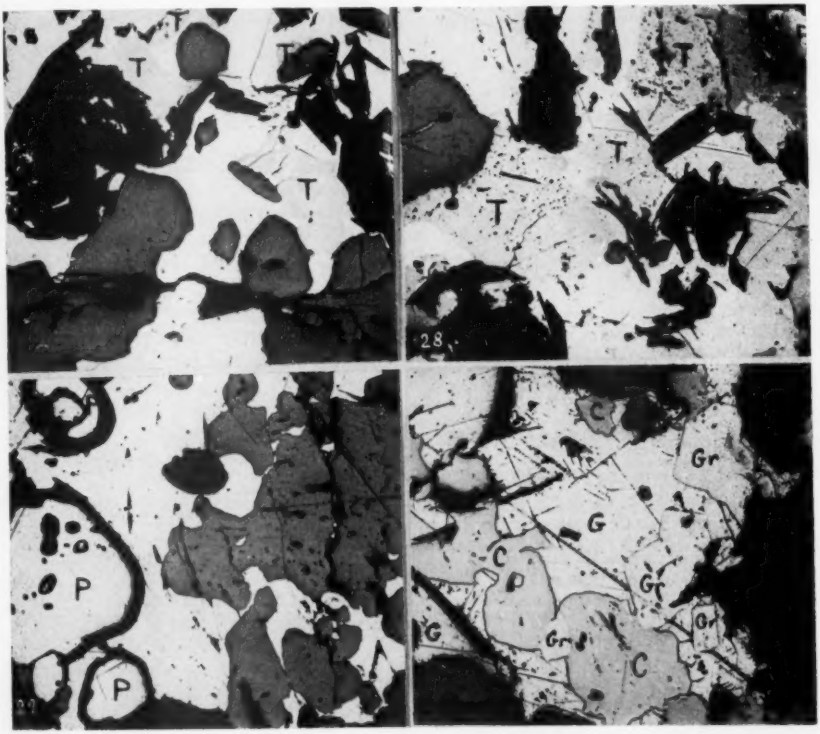


FIG. 27. Typical relations of ore minerals—sphalerite (dark gray), tetrahedrite (T), and galena (white)—and sericite and remnant sericitized quartzite (black). × 90.

FIG. 28. Corroded grain of pyrite (P), tetrahedrite (T) penetrated and replaced irregularly by galena (white), sphalerite (gray) and the ever-present coarse sericite (black). × 90.

FIG. 29. Crystals of pyrite (P) corroded by galena (white) and grains of sphalerite (gray) enveloped by galena. × 90.

FIG. 30. Rhombic crystals of gratonite (Gr) in galena (G) and chalcopyrite (C), developed therein by euhedral replacement. × 90.

In and near the granite the molybdenite is coarse, forming grains as much as one half inch long; but outward the size diminishes and grains become microscopic but so closely crowded as to form thin compact masses and coatings. The molybdenite is commonly accompanied by minute crystals of pyrite and tiny grains of chalcopyrite. Considerable molybdenite is contained in the micaceous seams and aggregates in or near the granite and penetrates and replaces the mica. Like the muscovite, it is caught up and more or less extensively replaced by the coarse-grained, white quartz (Fig. 17). At greater distances from the granite the more minute crystals of molybdenite are associated with sericite.

The molybdenite was associated with and accompanied the earlier minerals, but the greater part of it now is in fractures which cut the quartz. Apparently it has been sheared from its original position in veinlets where its easy cleavage and softness has facilitated movement.

Scheelite occurs sparingly in the mineralized granite and in the veins near the granite. That in the veins forms thin pale-yellow to white crusts and specks on the loosely interlocked coarse quartz crystals and small druses in cavities in the quartz.

Siderite occurs in very small amounts as small platy crystals covering fracture surfaces in the ore and as thin crusts lining open clefts. Its occurrence in the veins seems to be much like that of the scheelite.

Calcite is present in very small quantities in the ore as thin crusts in vugs and as minute fracture fillings. In places it accompanies and forms a thin coating on siderite and scheelite.

Paragenesis.

Although the minerals in the veins may seem to be so intimately intergrown as to suggest the absence of any definite sequence in their formation,[11] detailed microscopic study has shown this not to be the case. Instead of essential contemporaneity, the minerals were deposited in a fairly definite order as established by replacements and inclusions. The huebnerite, which, because of its good crystal form, had been regarded as one of the earliest minerals, proves, because of euhedral replacement, to be one of the latest. Actually there are two closely associated stages of mineralization, one responsible for the sulfides, the other for the quartz and tungsten. As pointed out earlier, the sulfide ore, which was deposited near the granite, has been incorporated in the later quartz-tungsten filling.

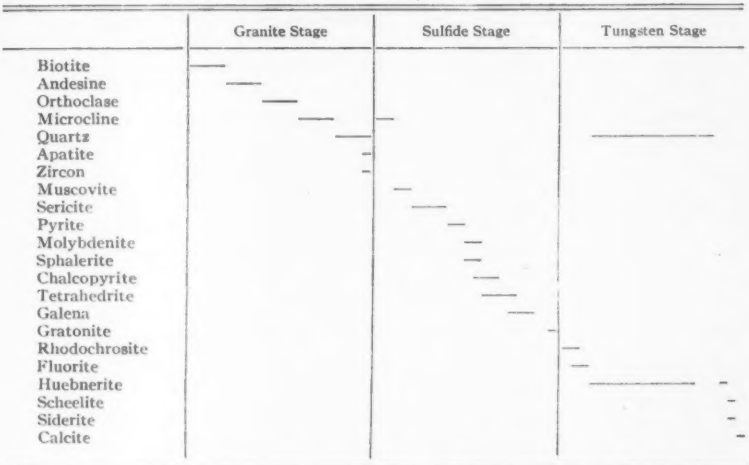
The microcline in the veins near the granite may well be the first mineral of the sequence. It is cut by thin seams of mica and molybdenite (with pyrite and a little chalcopyrite) and is caught up in the coarsely crystalline quartz of the quartz-tungsten stage. The muscovite and sericite were next, the muscovite forming in and close to the granite and hence under more intense thermal conditions than the sericite, most of which formed in the wall rock of the veins. After the micas came the sulfides, pyrite first and then the others. The position of the molybdenite is not entirely clear. It is younger than the

[11] Umpleby, J. B., U. S. Geol. Survey Bull. 528, op. cit., p. 111.

pyrite with which it is associated, but apparently while it was being deposited in and near the granite, other sulfides were being deposited farther away. Where the molybdenite occurs with the other sulfides, it appears to have been squeezed into them along fractures and therefore has moved from its original site. The other sulfides are so intimately intergrown as to be practical contemporaneous, but inclusions, fracture fillings, and replacements indicate overlap and a general sequence of pyrite, sphalerite, chalcopyrite, tetrahedrite, galena, and gratonite. All of these show replacement of fine-grained quartz and coarse sericite, apparently the sericitized quartzite.

TABLE 1.

MINERAL SEQUENCE.



The quartz-tungsten stage of mineralization appears to have been initiated by deposition of fluorite and rhodochrosite, the fluorite in and close to the granite, the rhodochrosite a little farther away. There was overlap in their distribution and locally fluorite aggregates cut the rhodochrosite. Both then were engulfed in the quartz-huebnerite filling, which also incorporated the sulfides. The quartz and huebnerite, singly and together, entered and replaced the earlier minerals, the huebnerite taking its own prismatic crystal form. The two were also deposited contemporaneously in open spaces, the quartz outlasting the huebnerite. Locally the filling was fractured and a second generation of huebnerite was introduced along the fractures. Mineralization ended with deposition of a little scheelite in the granite and vein openings near the granite and with addition of siderite and calcite as small druses in openings in the quartz.

The mineral sequence is shown diagrammatically in Table 1.

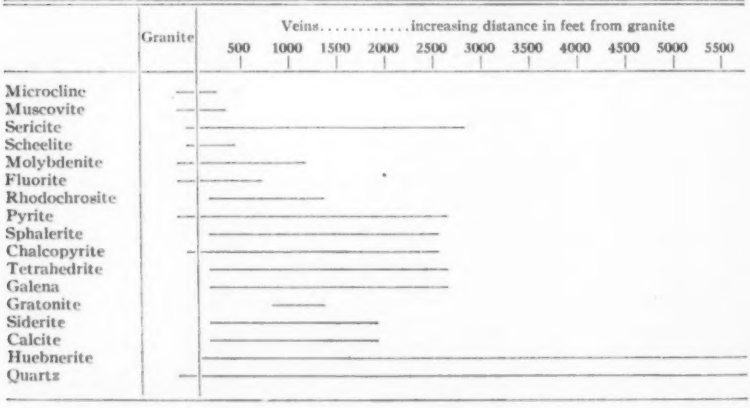
Zoning.

From what has gone before, it is obvious that many of the minerals are arranged zonally about the granite. Those found in and close to the granite are microcline, molybdenite, muscovite, fluorite, and scheelite; those that extend some distance from the granite are rhodochrosite, sericite, and the sulfides of lead, copper, and zinc; and those that persist to the outer limits of mineralization are quartz and huebnerite.

Neither the microcline nor the muscovite appears to persist more than a few tens of feet from the granite border, nor does the fluorite extend out for more than 600 feet. On the other hand the rhodochrosite begins near the granite and continues outward some distance beyond the fluorite. The molybdenite is most abundant in the granite and shows a notable decline with increasing distance from the contact. It and the associated muscovite also show a marked change in grain size from coarse in and near the granite to fine at greater distances. Some molybdenite was observed at least 600 feet from the contact on the lower mine level and as much as 1,500 feet upward from the granite, indicating that it has a greater vertical than lateral range.

TABLE 2.

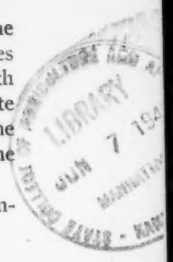
ZONAL DISTRIBUTION OF THE MINERALS.



Some pyrite was deposited in the granite but otherwise sulfide deposition began at the margins of the granite and extended out laterally for not less than 2,000 feet. A somewhat higher zinc content near the granite and somewhat more abundant lead near the outer limits of the sulfide zone suggest some zoning in the distribution of the sulfides. The present commercial range of this by-product ore is about 1,000 feet from the contact. The sulfides, except pyrite, show little change in grain size from the granite outward, but the pyrite is much more coarsely crystalline in and near the granite than it is farther away.

The huebnerite occurs rather sparingly in the quartz in and near the granite, but becomes relatively abundant outward, and with quartz continues for more than a mile from the granite, the outer limit of mineralization. Both quartz and huebnerite were deposited in larger volumes nearer the granite than farther out, giving rise locally to veins of exceptionally large size. The ore shoots are contained in these large veins within a few hundred feet of the granite.

The zonal distribution of the minerals about the granite is shown diagrammatically though somewhat idealistically in Table 2.



Genesis.

Role of the Granite.—That there is a close genetic relationship between the mineralization and the granite is indicated by the distribution of the deposits and the zonal arrangement of the minerals about the granite and by the increased intensity of mineralization near the granite contact. Study of the granite has revealed that it is not "magmatic" in the ordinary sense but is a replacement granite formed by "granitization" of quartzite. The granite is therefore itself a product of hydrothermal rather than magmatic processes, and, because of the close relation of the mineralization and granite, may represent an early intense type of wall-rock alteration with the sulfide and tungsten mineralization occurring as later and cooler phases of the same process. Consequently, both the granite and the ore may depend on hydrothermal solutions originating in a deeper magmatic source, and both may be looked upon as genetically very closely related products of mineralization, with the granite formed under early superintensive conditions.

Genetic History.—The early mineralizing solutions apparently contained a notable concentration of silica and alkalies and appreciable quantities of lime, magnesia, and iron. Possessed of a high degree of heat, these solutions on reaching the central, more extensively fractured part of the anticlinal arch entered and reacted with the quartzite, altering it to granite with successive formation of biotite, sodic plagioclase, orthoclase, microcline, quartz, and accessories. The alteration of the quartzite evidently proceeded on a descending thermal scale with the magnesia, some of the iron, and the lime being lost at the higher temperatures and with the potash and silica, at somewhat lower temperatures. The granite thus produced along the main channel has remained the focal point of all subsequent mineralization.

After the early-stage granitization, the solutions, still possessed of considerable potash and now also of metallic elements and sulphur, continued to ascend along the granitized zone and to spread out into the more abundant fractures in the bordering quartzite. These solutions introduced more potash into the still relatively hot granitic rock and the bordering quartzite, depositing microcline in fractures and forming muscovite and coarse sericite after biotite and sodic plagioclase. As the solutions moved outward along the fractures in the quartzite, where temperatures were lower and conditions less intense, the potash was added to the walls as sericite. With further drop in tempera-

ture sulfides were deposited. The relatively high temperature prevailing in and close to the granite favored the deposition of coarse pyrite and molybdenite, but farther out where temperatures were lower, the deposition of finer-grained pyrite and of the other sulfides was favored, chiefly by replacement of the sericitized quartzite.

After sulfide deposition, there appears to have been a general reopening of the mineralized fractures, particularly in the quartzite close to the granite, and the flow of silica-rich solutions carrying some lime, fluorine, manganese, tungsten, and carbon dioxide was begun. These solutions soaked into the granite but left only a minor amount of lime and fluorine as fluorite. They moved along the fractures in the bordering quartzite and left both rhodochrosite and fluorite. Then the tungsten carried by the silica-rich solutions began its deposition, with quartz and huebnerite coming out together in the fractures extending out from the granite. Near the granite the earlier sulfides were engulfed and incorporated in the quartz-huebnerite filling. Thus the commercially important silver-tungsten veins were formed close to the granite and the simple quartz-tungsten veins, at greater distances. Mineralization ended with the addition of a little scheelite in and near the granite and of siderite and calcite a little farther away.

Temperature and Pressure.—During the early intense stage of wall-rock alteration, when quartzite was changed to granite, temperatures were high but the absence of magnesium-lime-iron silicates indicates that temperatures usual under contact metamorphic conditions were not attained. The temperatures were, however, well within the hypothermal range. Thereafter temperatures showed a more or less progressive decline both at and away from the granite. At the start of the sulfide stage, temperatures were still high enough in and near the granite to favor deposition of microcline, muscovite, and molybdenite, but, while these minerals of relatively high heats of formation were being formed in and close to the granite, minerals of lower formational heats (sericite and sulfides) were being deposited in and along the fractures in the cooler quartzite, apparently under mesothermal conditions. During the tungsten stage, temperatures in and close to the granite were too high to allow much huebnerite to form, but farther out, where conditions were more nearly epithermal, huebnerite was deposited in relative abundance.

The pressure or depth at which the mineralization has taken place cannot be measured accurately. Erosion has probably stripped off several thousand feet of rock from the highest exposed croppings, and, with mining development, has uncovered the veins to an additional depth of 2,500 feet. The deposits show no evidence of rapid chilling such as characterizes many deposits formed near the surface nor do they show the extensive brecciation and fracturing commonly associated with such deposits. Except near the granite, filling of open spaces predominates over replacement and consequently deposition could not have taken place at very great depth. Because of the fairly abundant fracturing and the relatively steep thermal gradient, the deposits were probably formed at moderate depths below the surface.

Age.—The Ima mineralization is along the central arc that crosses New Mexico, Arizona, California, Nevada, Utah, Idaho, and Montana [12] and has many features in common with the Tertiary tungsten mineralization of the eastern arc, particularly in Colorado. For reasons that have been presented elsewhere,[13] the writer believes that the mineralization came at the close of the Laramide orogeny and that the deposits therefore are of early Tertiary age.

SUMMARY AND CONCLUSIONS.

The tungsten mineralization at the Ima mine is particularly notable for its intimate association with granitization and only less so for its many minerals and their complicated relationships. The granitization, which locally has converted quartzite to granite, apparently represents an early super-intense phase of wall-rock alteration that formed an essential part of the mineralizing process. With the granite as the "hot center," the mineralization outward was of decreasing intensity and resulted in zonal arrangement of many of the minerals.

Shortly after the granitization there came the stage of sulfide deposition with microcline, muscovite, pyrite, and molybdenite formed in fractures in and close to the granite and with sericite, pyrite, tetrahedrite, and other sulfides in openings at greater distances. After sulfide deposition came the tungsten stage with the tungsten carried by silica-rich solutions and deposited contemporaneously with quartz as huebnerite. Fluorite and rhodochrosite were deposited close to the granite and then with the sulfides were incorporated in the quartz-huebnerite filling. This gave rise to the ore of the complex silver-tungsten veins. Outward beyond the range of the sulfides, simple quartz-tungstein veins were formed.

The mineralization has other features of interest. Instead of having formed early as formerly supposed, the euhedral huebnerite crystals are among the youngest and owe their crystal outline to euhedral replacements of earlier minerals, including sulfides. The muscovite and sericite in the veins have been incorporated from earlier seams and micaceous aggregates which had formed in fractures in the quartzite and in the walls. The mineralization is further distinguished by the presence of the rare mineral gratonite, otherwise known to occur at Cerro de Pasco in the Andes Mountains of South America.

The Ima mine is not an isolated case of closely associated granitization and mineralization. Similar phenomena have been observed in the Nicholia district in the nearby Beaverhead Mountains where lead deposits occur about a body of granitized quartzite [14] and also near Leadore farther north where Paleozoic limestone has been granitized and then impregnated by pyrite and galena.[15] Much of the same sort of thing has also occurred at the Wilbert mine in the Lemhi Range a few miles southeast of the Ima where dolomite has been impregnated with feldspar during early stages of wall-rock altera-

[12] Kerr, P. F., Tungsten mineralization in the United States: Geol. Soc. America Memoir 15, pp. 5–9, 1946.

[13] Anderson, A. L.: Manuscript report, op. cit.

[14] Anderson, A. L., and Wagner, W. R., Lead-zinc-copper deposits of the Birch Creek district, Clark and Lemhi Counties, Idaho: Idaho Bur. Mines and Geology Pamph. 70, p. 9, 1944.

[15] Anderson, A. L.: Report in progress.

tion.[16] Thus, granitization as an early phase of mineralization may be much more common than has generally been recognized.

ACKNOWLEDGMENTS.

The writer wishes to express his gratitude to Professor E. S. Bastin of Ithaca, New York, for his kindness in reading the manuscript and in offering helpful suggestions.

DEPARTMENT OF GEOLOGY,
CORNELL UNIVERSITY,
ITHACA, NEW YORK,
Feb. 12, 1948.

[16] Anderson, A. L., Structural control and wall-rock alteration at the Wilbert mine, Dome district, Butte County, Idaho: ECON. GEOL., vol. 42, No. 4, pp. 368–383, 1947.

VARIABLE COALIFICATION: THE PROCESSES INVOLVED IN COAL FORMATION.[1]

JAMES MORTON SCHOPF.

ABSTRACT.

Coalification involves the genetic and metamorphic history of coal beds. The plant materials that form coal may be, in part, simply incorporated, or they may be present in vitrinized or fusinized form. Materials contributing to coal differ in their response to diagenetic and metamorphic agencies and the three essential processes of coalification are called incorporation, vitrinization, and fusinization. The processes are defined on the basis of important petrographic characteristics. A diagram is given illustrating the extent of change in the plant material, in comparison with diagenetic and metamorphic intensity. Since coal beds generally include various proportions of the diverse materials resulting from the three processes, practical classification of coal is intimately related to the part each process has played.

GENERAL CONSIDERATIONS.

THE character of coal in any deposit is a result of the collective influence of the processes that formed it. Differences in the history of the formation of a coal bed are therefore reflected by differences in its present lithology, composition, and properties. Initial differences result from the association of plant life and the environmental factors that influence their growth, death, and degree and manner of decomposition. A close relationship exists between local environment, site of growth and decay, and the consequent accumulation of diverse kinds and assemblages of vegetable remains as peat. The diversified chains of physical events that are included in "peat accumulation" are matched by processes of chemical and biochemical nature throughout the early history of the deposit. It is believed that these attendant chemical processes are decisive in determining essential modes of incoalation.

All of these initial phases in the history of the coal deposit, up to the time the plant material is consolidated and biochemical activity greatly diminished by restricted mobility of the medium, may be included in the stage of diagenetic alteration.

In the succeeding history of a coal deposit, earth pressures, metamorphic in magnitude in relation to physically weak rocks such as coal, become more and more a dominating factor.

Coal, as such, is first formed by diagenetic compaction of peat, but the boundary between peat and coal (brown coal) is not sharp. An arbitrary distinction between coal and peat, based perhaps on coherence and moisture relationships, might be devised, but understanding of the causal relationships

[1] Published by permission of the Director, U. S. Geological Survey, and presented before the Society of Economic Geologists, Ottawa Meeting, December 1947.

involved in coalification includes both the diagenetic and the metamorphic phases.

An ultimate aim of coal petrography is an understanding of the causal relationships between the different varieties of coal insofar as these can be detected by megascopic or microscopic study—in other words, *why coals differ*. A more primary concern, of course, is in defining *how* coals differ; and a more practical concern, and one which necessarily involves active collaboration with other branches of fuel technology, is in determining the effect and significance of petrographic differences with regard to various utilization properties.

Two different classes of petrographic entities have been recognized in coal. Those based on recognition of plant fossil parts and pieces have been called phyterals by Cady.[2] Possibly some kinds of decomposition products could also be included as phyterals, in the sense that they are fossilized remnants distinguished by their biologic origin. Phyterals persist throughout the metamorphic stages of coal formation. Their identity remains constant although their composition varies. Recognition of a particular phyteral usually becomes more difficult with advanced metamorphism because of technical difficulties in observation. The phyteral composition of a coal ordinarily is fixed at the beginning of coalification or towards the end of the peat stage, and subsequent changes of physical and chemical nature caused by metamorphism can be identified on a more precise basis by referring to the stable assemblage of phyteral or plant fossil constituents.

Entities recognized by virtue of chemical and physical similarity correspond with macerals as defined by Stopes in 1935.[3] Macerals are identified on the basis of similarity in composition, as are minerals. The same type of phyteral may be represented by several macerals differing in composition; such differences necessarily exist if similar phyterals are compared from coals sufficiently different in rank (*i.e.*, degree of metamorphism). Likewise, the same maceral may be constituted from diverse types of phyterals. Probably the greatest practical significance is to be found in the chemical and physical alteration of phyterals, because at certain stages of metamorphism the macerals formed by compositional changes have very different properties. These changes entirely alter the suitability of coal for various uses.

Only a few of the common petrographic terms applied to constituents of coal have either a purely botanical, *i.e.*, genetic, or a very precise compositional implication. Several of the entities, such as translucent attritus, durain, and clarain, are mixtures of phyterals and macerals, according to arbitrary systems that are dependent to some variable degree on lithologic as well as phyteral and maceral criteria. Quantitative petrographic data cannot be accurately interpreted unless the conditions of original analysis are well appreciated. Furthermore, the theoretical imperfection of the entities must be clearly recognized if their relative and comparative significance is to be properly evaluated. The application of the general terminology of coal petrography cannot be dis-

[2] Cady, G. H., Modern concepts of the physical constitution of coal: Jour. Geology, vol. 50, pp. 337–356, 1942.

[3] Stopes, M. C., On the petrology of banded bituminous coals: Fuel in Science and Practice, vol. 14, pp. 4–13, 1935.

cussed in the present paper except to remark that the writer believes that even the theoretically more imperfect terms, most of which have arisen from practical analytic need, have definite value for certain types of descriptive petrographic analysis.

Thin sections, such as those customarily prepared in the Bureau of Mines Laboratory in Pittsburgh, afford possibilities for high refinement in coal petrographic studies. The quality of coal thin sections depends to a great extent on consistently making the coal thin enough for optimum resolution of detail. Well-made sections, of course, also generally include a large enough slice of coal so that an excessive number will not be required for quantitative microscopy. In the writer's experience, it is usually impractical to prepare sections of requisite quality larger than about an inch square. However, the emphasis in preparation of thin sections of coal always should be on the resolution of optical detail under the microscope rather than on total area or general megascopic appearance of the preparations. The technique of preparing coal sections has been described on several occasions,[4] and many undescribed variations in technique are possible whereby the experienced preparator can obtain optimum results, depending on the material. It should also be stated that, while consistently uniform sections are required for accuracy in certain systems of petrographic analysis, studies as accurate in a qualitative sense can be made from sections less expertly prepared, provided that judgments are based on selected microscopic areas that are thin enough for resolution of *critical detail.* This necessarily requires a greater skill and interpretative facility on the part of the microscopist than if sections of consistently uniform quality are always available.

The petrographic variations in coal described in this paper have been observed in thin sections where critical resolution was possible. Sections prepared by the Thiessen technique are not chemically treated in any way. Thus there is no question structures observed are native to the coal, and the preparations can usually be made rapidly. The chief advantage of this method of preparation and observation of coal, over methods employing single-surface polishing and observation with reflected light, is that the differential physical qualities of light transmission by different constituents are so precisely visible. The brilliance and degree of color contrast between the different entities permit more definite and reliable identification at high magnification.

Such differences are only partly evident in photomicrographs or in ordinary halftone illustrations where color values become shades of gray and thus afford no adequate basis for independent identification. Perhaps for this reason and because details of form always are present to confuse the issue, the importance of differential color transmission as a basic means of identification has not been sufficiently appreciated. At the present time it is impossible, in fact, to form an objectively independent opinion of work in coal thin-

[4] Thiessen, Reinhardt, Structure in Paleozoic bituminous coals: U. S. Bur. Mines Bull. 117, pp. 10–12, 1920. Thiessen, Reinhardt, Sprunk, G. C., and O'Donnell, H. J., Preparation of thin sections of coal: U. S. Bur. Mines Inf. Circ. 7021, pp. 1–8, 1938. Stutzer, Otto, Geology of coal, translated and revised by A. C. Noé, pp. 51–55, Chicago Univ. Press, 1940. Schopf, J. M., Botanical aspects of coal petrology; coal from the Coos Bay field in southwestern Oregon: Am. Jour. Botany, vol. 34, pp. 335–345, 1947.

section petrography without first-hand observation of similar sections. Nonetheless, the color transmission differences are of critical importance and are the basis of much of the succeeding discussion.

The apparent color transmission varies for all constituents of coal, depending on the thickness of the thin section. Perhaps it is improper to regard any of the organic part of coal as "opaque" because all constituents can be made to transmit light if the coal is thin enough. Opaque attritus, fusain, and highly metamorphosed anthracite are least translucent, but they appear grayish when present as films considerably less than a micron thick. No coal constituents show perceptible color (apart from grayness) if metamorphism has reduced the volatile matter to less than 6 or 7 per cent.[5] Color can be definitely detected in some lowest-rank anthracite (8 per cent volatile matter) and in all less metamorphosed coal. Sections adequate for normal quantitative study are usually not prepared for coals of higher rank than low volatile bituminous because such coal is so dense sections cannot be ground thin enough for visibility without excessive loss of area and perforation.

Coal in the upper range of low-volatile bituminous rank must approximate a thickness of about 5 microns or less if it is to transmit light to a satisfactory degree for critical observation. Satisfactory definition of structure and color is obtained in high-volatile bituminous coal if sections are prepared 8 to 12 microns thick. Lignite usually shows satisfactory translucence if it is as thin as 15 to 20 microns.

Such statements regarding thickness are, of course, approximations since it is very difficult to precisely determine the absolute thickness of coal in a section at any particular point. Measurement using the fine focusing adjustment usually is not accurate beyond a tolerance of about 5 microns, and, while it is simple to obtain a sharp focus on the upper surface, with material as dense as coal it is very difficult to be certain of a sharp focus in the plane of the lower surface of a section. Differences in color transmission due to variations of section thickness are visible to a much more refined degree than the error inherent in estimation of section thickness by any absolute method yet devised. It is chiefly for this reason that no precise photometric method has been developed in preference to the visual interpretation of relative section thickness by the coal petrographer.

Using color-transmission characteristics as a primary criterion, three substantially different kinds of coalified material can be recognized. They are intimately related to the constituent phyterals and macerals and to identification of some of the standard micropetrologic entities. They can be demonstrated in coals of all ages from all over the world [6] that have been affected by

[5] Jeffrey has reported (Am. Acad. Arts Sci., Mem. 15 (1), pp. 33–34, 1924) preparing useful microtome sections of anthracite embedded in celloidin, following months-long treatment in strong reagents to soften it and remove mineral matter. There is no question that high-rank coal can be sectioned by this method and that color transmission differences can be seen, but Jeffrey did not provide chemical analyses of untreated coal matching that which was sectioned, and the localities from which his coal came are stated only generally, so a question still remains as to the actual rank of the "anthracite" that he sectioned.

[6] The writer has personally made observations on specimens from major coal fields of North and South America, Australia, Triassic coal from fields near Chunking, China, and most commercial coals from South Africa. German and English coals were investigated by Thiessen, among others, to fully prove the qualitative similarity of these deposits. The atlas of Russian

incipient and moderate metamorphism. Related variations persist into higher rank coal, but extreme metamorphism minimizes the diversity of composition (hence of macerals) and increases the difficulty in identifying some types of phyterals.

LIBRARY JUN 7 1940

The color-transmission characteristics are reflected in the physical properties of coalified substances and in their preservational form judged as botanical entities. Viewing the heterogeneity of coal from a dynamic standpoint, it appears reasonable to regard the different classes of petrologic composition as due to diverse incoalation processes, each of which predicates a different trend of alteration during the diagenetic and metamorphic stages.

At this point the writer wishes to emphasize the distinction between *processes,* as such, the *things* effected by processes, and the *agencies* that are instrumental. If coal petrographic theory is to progress in regard to the causal relationships of coal varieties, attention should be clearly focused on the manifestations of the processes in a dynamic fashion consistent with the present-day knowledge of its composition and its antecedent history. Agencies, things, and processes are usually not independently identified in discussion of coal constituents, but the writer believes it is important to do so if our theoretical knowledge of coalification is to be extended commensurate to advances in coal petrography and coal constitution during the last 20 years. For this reason the following discussion has been prepared with regard to particular processes, all of which are implicit in the general term, coalification or incoalation. The three terms chosen with reference to the entities in coal that typify them are: fusinization, vitrinization, and incorporation.[7] The last-named process, incorporation, will be treated first.

The coordinate relationships between the three processes, as they pertain to the evolutionary history of any normal coal bed, have been sketched on the accompanying diagram Fig. 1, and may be conveniently referred to in elucidation of succeeding textual discussion. It appears that an element of predestination enters into the series of developmental changes through which each coal bed, to some extent, has progressed. Once a botanical or decompositional entity of a peat deposit has been started on its path of alteration, its subsequent progression through a definite type of cycle seems assured for its geologic duration. Probably many predictive relationships about these sequences of changes are yet to be discovered.

coals, including color photolithographic reproductions of detailed camera lucida color drawings (artist, V. A. Franck) from thin sections, that was published under the editorial supervision of Zhemchuznikoff and Ergolskaya in 1937 ("Atlas of microstructures of the USSR coals," including complete English translation by E. M. Glass, edited by A. N. Kryshtofovich. Central Scientific Geological Prospecting Institute, General Geological Service, fascicle 101. Text, 185 pp.; atlas, 60 pls., 102 figs. Leningrad and Moscow, 1937. Available in America at the U. S. Geological Survey library—call no. (570), Tc, No. 101) shows convincingly that coals of the numerous Soviet coal districts possess the same qualitative kinds of constituents as those of the rest of the world.

[7] The first-named terms have had sporadic use by various authors, who have, however, employed them in the more proper etymologic form as "vitrainization" (or isation) or "fusainization." The writer prefers the modified spelling chiefly for sake of euphony and because fusinitization and vitrinitization, which are more pertinent to the true meanings intended here, seem unduly lengthy. The writer believes that technical terminology should be distinguished from a formal nomenclature and that the former can be more effectively employed with a certain liberality in etymologic considerations.

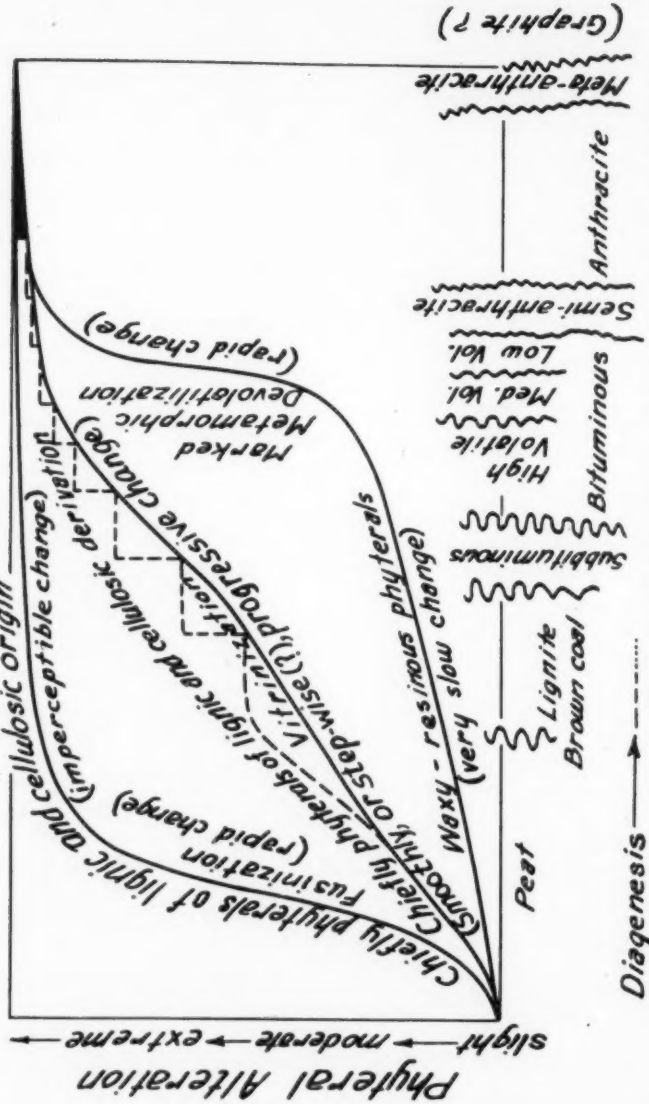


FIG. 1. The metamorphic alteration of phyterals, diagrammatic.

COALIFICATION BY INCORPORATION.

Frequently it is overlooked that some substances become a part of coal (and are, therefore, "coalified") without undergoing any material modification. For want of a better term, this process may be spoken of as incorporation. In the sense used here, the term does not apply to materials that have been diagenetically altered.

The phyterals chiefly recognized that are subject to incorporation in coal are pollen and spore coats, plant cuticles, suberized lamellae, thimble cups of *Botryococcus* (boghead oil algae), and certain of the secretory inclusions of plants.[8] In some coals disseminated yellow waxy matter occurs, and sometimes free amberlike blebs of lump resin are present.

The initial composition of these plant materials is evidently important in determining this mode of preservation; the materials by nature are resistant to alteration. Pollen and spore coats, plant cuticles, suberin, etc., are of waxy or fatty character in living plants, and their relative stability may be demonstrated in various ways. Many forms can be isolated from the rest of the coal by chemical processes, and distinctive types are being used as plant microfossils. Blebs of resin in younger coals are evidently related to the terpene resins and to amber, a well-known fossil resin. This assemblage of phyterals in coal, which have certain petrologic characteristics in common, may, for convenience, be spoken of as the waxy-resinous phyteral group. Their suggested path of metamorphic alteration in coal is indicated by the lower of the three curves sketched in the accompanying figure.

During the diagenetic and early metamorphic history of a coal deposit the waxy-resinous phyterals undergo very slow and relatively imperceptible change in composition, and the materials composing them are identified with the macerals exinite, cutinite, and resinite (Stopes, op. cit., footnote 3). The point in question is whether in coal these named macerals differ in composition sufficiently to merit recognition, or whether all the waxy-resinous phyterals, in certain coals at least, may not be similar enough to be amply described under the single maceral designation as exinites. Some authors have adopted the latter course. The various botanical characteristics of the different forms is usually definite enough, particularly in coals of Paleozoic age, but, although differences exist, there is little information that will serve as a distinction on the basis of actual composition rather than botany.

The waxy-resinous phyterals in low- and medium-rank coals show evident similarity to comparable portions of living plants or to those from raw peat. Zetzche and coworkers[9] have shown significant similarity between modern and very ancient spore-coat materials, none of which, however, had been highly metamorphosed. Fisher, Sprunk, et al.[10] have presented data regarding hy-

[8] Not all plant inclusions found in coal, and not all that have on various occasions been called "resinous," are subject to incorporate preservation. Some very common types generally are coalified in other ways.

[9] Zetzsche, F., Vicari, H., and Schärer, G., Untersuchungen über die Membran der Sporen und Pollen, IV. 3. Fossiles Sporopollenin aus dem Tasmanit und der Moskauer Braunkohle: Helvetica Chimica, Acta, vol. 14, no. 1, pp. 67–78, 1930.

[10] Fisher, C. H., Sprunk, G. C., Eisner, A., Clark, L., Fein, M. L., and Storch, H. H., Hydrogenation of cannel coals and their petrographic constituents: Fuel in Science and Practice, vol. 19, no. 4, pp. 84–89, and no. 5, pp. 110–118, May and June 1940.

drogenation characteristics of materials corresponding to waxy-resinous phyterals. Their samples included (1) commercial lycopodium (chiefly spore coats, modern), (2) spore coats separated from a bituminous rank coal of Pennsylvanian age, (3) fossil lump resin from a bituminous rank coal of Cretaceous age, (4) natural resin, which filled a cavity in modern coniferous wood, (5) fossil algal material (Kukersite—remains of *Gloeocapsomorpha prisca*) from an "algal" shale and limestone deposit of Ordovician age. All of these responded similarly to mild hydrogenation treatment and are more responsive than coal samples, including other and differently preserved types of phyterals. The hydrogenation products derived from waxy-resinous phyterals or their modern equivalents also are different from coal in gross samples and yielded oils containing greater amounts of saturated hydrocarbons. None of the fossil materials investigated was strongly metamorphosed, and the data support the belief that the waxy-resinous phyterals composing the macerals exinite, cutinite, and resinite have similar petrologic significance through the lower-rank metamorphic stages. If significant compositional differences can be detected it may, of course, be desirable to draw the boundaries more sharply or to recognize additional specific macerals.

The waxy-resinous phyterals of lignite, sub-bituminous coal, and high-volatile bituminous coal show exceptional optical translucency in thin sections. They are generally a brilliant yellow, although in lignite some resinous bodies are almost colorless or hyaline in properly thinned sections. When observed by diffuse reflected illumination they are more generally brownish, although the tone varies considerably. In the upper range of high-volatile bituminous coal they tend to be darker hued. They seem always to have a dull luster.

The waxy-resinous phyterals are evidently considerably changed in composition by the higher intensity of metamorphism required to form low-volatile bituminous coal, since in low-volatile coal there is no evidence of yellow coloration. None of the other phyterals composing coal shows a similar great modification in microscopical characteristics during alteration to low-volatile rank. The writer believes this rather marked and abrupt change in the waxy-resinous constituents has not been sufficiently emphasized in view of the well-known differences in utilization properties of low-volatile as contrasted with high-volatile bituminous coal. Intermediate stages can sometimes be detected in medium-volatile bituminous coal, and this provides a general indication of the metamorphic stage at which this visible alteration in composition and optical properties takes place. More precise criteria than are afforded by the ordinary samples used for chemical analyses are needed in order to define the visible alteration stage more precisely.

Observations of the change in waxy-resinous phyterals have been made in a limited number of medium-volatile bituminous coals (Sewell, Fayette County, W. Va., see U. S. Bureau Mines Mon. 5, 1934; Cumnock Deep River coal field, N. C.; Lower Freeport, eastern Indiana County, Pa., see U. S. Bureau Mines Tech. Paper 621; Bakerstown and other coals, Georges Creek basin in western Maryland, see U. S. Bureau Mines Tech. Paper 644), and these usually appear to resemble low-volatile bituminous coals in the lack of definite yellow transmitting materials. However, the shade of color transmission is

slightly lighter than the associated anthraxylon in some instances. Observations on South African coal affected by igneous sills at variable distances from the coal show the same type of alteration in waxy phyterals as in coals altered by pressure in eastern United States. The change appears to occur in coal within the range of 23 to 25 per cent volatile matter.

All the high-volatile bituminous and lower-rank coals that have been examined show definite indication of yellow brilliant light transmission by the waxy-resinous phyterals, which is in striking contrast to the red anthraxylon. This property has been noted by Thiessen and other authors on a number of occasions.

A number of coals with typical low-volatile bituminous characteristics have been examined (Beckley, Raleigh County, W. Va., see U. S. Bureau Mines Bull. 411; Lower and Upper Kittanning, Cambria County, Pa., see U. S. Bureau Mines Tech. Paper 595; Sewell, Wyoming County, W. Va., see U. S. Bureau Mines Tech. Paper 601; Pocahontas No. 3 and Pocahontas No. 4, see U. S. Bureau Mines Tech. Paper 604; Lower Hartshorne, Le Flore County, Okla., see U. S. Bureau Mines Tech. Paper 667; Upper Freeport (cannel coal), Somerset County, Pa., and two coals of semi-anthracitic rank, Meadow Branch coal field, Berkeley County, W. Va.; Monahan Coal Co. mine, Bernice basin, Sulivan County, Pa.). None of the low-volatile bituminous or semi-anthracitic coal shows preferential transmission of yellow light by waxy-resinous phyterals even in the thinnest areas of normal sections.

Botanical entities can be identified in sections of low-volatile bituminous coal by their morphologic characteristics, and it is evident that the same phyterals are represented as in lower-rank high-volatile coal. The spore coats and related phyterals in low-volatile coal are deeply red translucent, and they generally show exactly the same sort of light transmission as the anthraxylon and other vitrinized material (discussed below) that is associated with them. The more metamorphosed coal completely lacks yellow, or even orange coloration, when viewed normally in thin sections using transmitted light. Structures resembling spore coats that may be observed in semi-anthracite sometimes are darker than the associated anthraxylon and some of them even have a brownish hue.

These changes evidently should be interpreted as compositional alteration occasioned by metamorphism, and, according to this view, exinite and its allied macerals of lower-rank significance would not be present in coals of low-volatile bituminous or higher rank. There is a question whether the red-translucent spore coats should be identified with one of the vitrinite macerals on account of their color resemblance to high-rank anthraxylous materials, or whether a new maceral should be named. Quantitative discrimination of all the high-rank waxy-resinous phyterals is difficult in the absence of a color distinction that will assist in identifying broken fragments of somewhat indefinite form. From the practical petrographic standpoint, grouping with vitrinized materials would be expedient. It is unnecessary to decide at the present time how these phyterals could best be treated, so long as the rather sudden change in their optical and probably compositional character is fully recognized.

The change in composition is indicated in Figure 1 by the abrupt upswing

of the waxy-resinous phyteral curve opposite the medium-volatile position of the metamorphic scale.

In anthracite the composition of the waxy-resinous phyterals probably is much the same as the rest of the coal, although some of the botanical characteristics of spore coats can still be demonstrated.[11] Incorporation with little change is characteristic of the waxy-resinous phyterals only through the high-volatile stage of metamorphism.

COALIFICATION BY VITRINIZATION.

The vitrinization process distinguished here is intended as a generalized concept and one which probably embraces a considerable diversity. It deserves particular emphasis, in petrologic considerations at least, because the greater part of most coals consists of vitrinized material. Since it is so generally abundant, and of all portions of coal is the most readily obtainable in fairly pure form, general concepts of coalification apply most directly to it. At the present time it seems advisable to define vitrinization in retrospective fashion as the process responsible for petrologic differentiation of the group of materials (phyterals and macerals) included in vitrinite, anthraxylon, and vitrain. In the present discussion vitrinization is considered an active process applying through all diagenetic and metamorphic stages of coal formation, thus including brown coal, lignite, sub-bituminous, bituminous, semi-anthracitic coal, and anthracite.

Stopes [12] has suggested that the term vitrain should be restricted in application to coals of bituminous rank, and by implication it might be thought the related vitrinization concept should be similarly confined. However, the writer believes the process of vitrinization is justifiably extended to include all ranks of coal with little qualification. Standard methods for determining rank have an arbitrary basis quite apart from petrographic considerations, and the restriction of a petrographic term in accordance with the non-petrographic expression of rank, as is involved in the standard definition of "bituminous" coal, does not seem entirely appropriate. The term vitrain should be applicable wherever its definite petrographic characteristics, such as relative brilliance, conchoidal fracture, and banded or lenticular occurrence, are present.

In brown coal or lignite, bands (lenses) occur that obviously are the antecedent homologues of typical vitrain in coal of higher rank and which accord perfectly with the microanalytic concept of anthraxylon; however, the distinctive luster and characteristic fracture of vitrain are wanting and ordinarily do not appear in coals lower in rank than sub-bituminous. Perhaps conflict with the objective petrographic definition of vitrain may be avoided if its homologue in the lowest ranks of coal is distinguished as pre-vitrain. Seyler,[13] however, has not hesitated to apply the term vitrinite to a component

[11] Turner, H. G., Microscopical structure of anthracite: Am. Inst. Min. Met. Eng. Trans., vol. 71, pp. 127–148, 1925.

[12] Stopes, M. C., On the petrology of banded bituminous coals: Fuel in Science and Practice, vol. 14, no. 1, pp. 4–13, 1935.

[13] Seyler, C. A., Recent progress in the petrology of coal (Melchett Lecture, October 1941): Inst. Fuel Jour., vol. 16, no. 90, pp. 134–141, June 1943.

(one which would be regarded definitely as vitrinized) he identified in Greek lignite, in spite of its dull luster and the evident woody structure of the specimen. The nature of the vitrain-vitrinite homologue (anthraxylon) in low-rank coal seems fairly understood, and the chief uncertainty is with regard to appropriate and consistent terminology.

The most brilliant and uniformly lustrous bands, having pronounced conchoidal fracture, etc., occur in anthracite. Apparently, judging from some references to anthracite, in certain instances this high-rank coal is so uniformly brilliant that its inherent banding is not evident. Much of the American anthracite is very prominently banded, and the identity of vitrain in such coal is beyond question if petrographic features, rather than arbitrary criteria of rank, are given full consideration.

It seems therefore, except for terminologic qualification with reference to lowest-rank coal, that the related petrographic terminology and the vitrinization concept in particular, are appropriate and applicable to all stages of coal formation beginning with consolidated peat.

All types of cellular tissues and some of the kinds of indigenous plant inclusions and secretions may appear in vitrinized preservation in coal. Colloidally dispersed humic matter, when present, doubtless is affected by the same process. Leaves and other fossil plant parts found isolated in coal-measures rocks, of the type called "compressions" by paleobotanists, generally consist of vitrinized matter, exclusive of their cuticles and other adherent or immersed waxy portions. Probably the principal plant materials are lignocellulosic or cellulosic, since the greater part of the vitrinized coal (anthraxylon) has been shown by researches of Reinhardt Thiessen and his coworkers, and others, to come largely from the cell walls of plant tissues. Cellulose and lignin in various associations and combinations predominate in the cell walls of higher plants with no significant exceptions.

Cellulose is a relatively unstable compound; nevertheless microscopic studies of coal permit little question that cellulosic materials originally were present and still are represented by various residues and alteration products. Lignin tends to be more stable chemically, but it is not supposed that any truly unaltered substances are present in the vitrinized portions of coals of bituminous or higher rank. Well-preserved vitrinized specimens may show all cell-wall portions that are observable in modern plants, and it seems reasonable to believe, therefore, that substantially all substances that are present in such parts of modern plants can contribute in some degree to coal. Doubtless some materials are lost and others differentially reduced in tissues that have suffered appreciable decay and degradation, so the actual proportional contribution by specific cell-wall substances to any coal deposit would be difficult to estimate.

During formation of peat the cell-wall substances, reacting to biochemical dissolution and decay, are said to be humified. If disintegration is arrested and the plant material becomes compacted, the slow process of vitrinization is initiated.

Vitrinization seems chiefly to involve a certain trend of chemical modification and transmutation of cell-wall substances, a subject largely in the field

of organic chemistry, which the writer is not qualified to discuss. The important petrographic contrast is with reference to fusain and with the process of fusinization. Both of these processes affect the same types of phyterals, and differentiation of fusinized and vitrinized macerals evidently occurs early in the peat stage. Vitrinization is regarded as a relatively slow process largely resultant from metamorphic alteration, whereas fusinization is principally, if not entirely, the result of early and rapid change. In a sense, the vitrinized materials are residual after a certain, usually minor, amount of the initially humified materials has been more radically and rapidly altered to form fusain and its allied macerals. Hence, vitrinization may be regarded as diagenetic in its inception, although the major part of the process is actuated by metamorphism as the composition is changed over a long period of time.

Vitrinized tissues are generally distorted by early compression, but the cell walls are not broken. Discontinuities may appear within the tissues owing to degradation in the peat stage, but vitrinization is characterized by indication of plastic adjustment of the walls, tending toward gradual elimination of cell cavities and interstitial tissue spaces; not by localized fracture. These effects are due in part to loss of physical strength and in part to the continual pressure of overburden. Thin-walled cellular tissues are naturally least competent and also are less frequently lignified, so that compression effects are first apparent in tissues composed of thin-walled cells. Thick-walled tissues may still show partially open lumens in lignite, but the early course of events tends toward elimination of the microscopic pore space. Softening of the tissues, which would facilitate early elimination of visible pores, is probably variable, depending on the extent of early biochemical change. In advanced lignites the lumens of even the most competent tissues are generally tightly closed, either by simple wall-to-wall compression or by moulding of the walls around various cellular inclusions. Tissue structure resolvable in coals of higher rank shows that imperceptible spatial adjustment occurs after the microscopic pores have been eliminated.

Tissues undergoing vitrinization show progressive decrease in translucency with increasing metamorphic alteration. Distinctive color transmission is the most important criterion for recognition of vitrinized materials in micropetrography. Thin sections of vitrinized phyterals (types of anthraxylon, etc.) are highly translucent in lignites and seem to show greater microscopical detail if prepared thicker than is desirable for higher-rank coal. The coloration generally is yellow to orange in thin areas of lignitic anthraxylon, but the shade of coloration seems always to be at least slightly darker than the associated waxy-resinous phyterals. Cell walls generally are not uniformly translucent but show zonation distinguishing at least the middle lamella and frequently two or more zones in the secondary wall. This type of zonation persists in bituminous coal and is still visible but much less conspicuous in semi-anthracite.

Vitrinized materials in bituminous coal are strongly red-translucent and generally so dense that sections should be finished 5 to 10 microns thick, depending on the actual rank, for best resolution of microscopic detail. Deep-red coloration is most characteristic of vitrinized matter in coals of low volatile

bituminous rank. Sections of semi-anthracite and lowest-rank anthracite show progressive increase in density to transmitted light, but in the thinnest feather-edge areas red coloration is still visible. Similar materials from higher-rank anthracite, with less than 6 or 7 per cent volatile matter, show no perceptible transmitted coloration. The thinnest feather edges of prepared sections may show a narrow marginal band with faint grayish translucency.

By many criteria the metamorphism of vitrinized materials appears to be smoothly progressive. Moisture and volatile matter tend to decrease, carbon content to increase, and the chemical maceration of coal of various ranks suggests a progressive decrease in chemical reactivity. In anthracite, vitrinized materials tend to resemble fusain in compositional (not morphologic) characteristics. The path of progressive vitrinization is indicated according to these conventional criteria by the heavy central curve sketched in the accompanying diagram. Recently, however, a different interpretation of the path of vitrinization, in the sense discussed here, has been advanced by Clarence Seyler.[14]

Study of the micro-reflectance of vitrinite from coals representing a wide range of rank has led Seyler to conclude that, with increasing metamorphism, reflectance values, at least, progress in an orderly but discontinuous, stepwise succession. Observations have been made with an evident high degree of refinement and precision, employing a moderate-magnification oil-immersion objective lens and the Berek slit microphotometer. With this equipment Seyler finds it possible to distinguish specific reflectance values for unit areas tiny as a single thickness of vitrinized cell wall. It may be this extreme of sample selection for individual reflectance determinations accounts for the differences in reflectance data Seyler has obtained from those of other investigators who employed larger unit reflecting areas.

Seyler believes vitrinization proceeds through nine separate and distinct steps (as shown by reflectance) in alteration of coal from lignite to anthracite. Vitrinite of several reflectance stages may be associated in any coal-bed locality at a given time. Further metamorphic alteration results in the progression of constituents to successively higher steps of the reflectance series until all the vitrinized material has the highest reflectance value recognized. The highest reflectance value Seyler has recorded from vitrinized material is similar to that of fusinite. The steps sketched in broken line above the general curve of vitrinization in the diagram approximately represent the reflectance stages indicated by Seyler.

These findings are of much interest in view of the importance that must attach to a petrographic method that promises to indicate the composition of specific coal materials within narrow limits. At the present time the fundamental significance of Seyler's results is difficult to assess. They have not yet been independently confirmed by other investigators, and the results are in striking contrast to the previous general understanding of the properties of coal. It is not inconceivable that vitrinized material may exhibit continuous

[14] Seyler, C. A., Recent progress in the petrology of coal (Melchett Lecture, October 1941): Inst. Fuel Jour., vol. 16, no. 90, pp. 134–141, June 1943. Seyler, C. A., The relevance of optical measurements to the structure and petrology of coal., pp. 270–289, *in* "Proceedings of a Conference on the Ultra-fine Structure of Coals and Cokes," published by the British Coal Utilization Research Association, Rickett Street, London, S.W. 6, 1944.

variation in many characteristics and discontinuous variation in certain other respects. If the latter course is verified with regard to specific reflectance, it may well provide an initial key to understanding the molecular evolution of the vitrinized macerals. From a purely petrographic standpoint, Seyler's work would seem to emphasize the importance of units of microscopic magnitude, in contrast to other variations involving units of ultramicroscopic or of megascopic dimensions.

COALIFICATION BY FUSINIZATION.

The process resulting in formation of fusain probably is complex, but it has the appearance of relative simplicity to those who believe it can be accounted for as fossil charcoal. Of the three coalification processes, fusinization evidently involves the most rapid and extreme change from the composition of original plant material. Whether fusain is properly interpreted as fossil charcoal or not, it is apparently present in some types of peaty deposits, and, although it is not present in all, it is found in coal of all ranks and all geologic ages. The salient fact of fusinization itself and the amount of fusinized material present is of more practical petrographic concern than the causal theory as to its origin.

Microscopic study of fusinized tissues in a wide variety of coals shows some features that are difficult to reconcile with the fire-char theory, but other theories that have been suggested also meet with various objections. There is, however, substantial agreement that plant tissues were altered to form fusain very early in the coalification sequence before overburden accumulated. Thus fusain should be regarded as diagenetic in origin even though the cause of the process is controversial. It also follows that metamorphism plays no essential part in the fusinization process.

The same types of plant materials and substances in peat that are capable of vitrinized preservation also seem to be susceptible to fusinization. The waxy-resinous phyterals are not commonly involved, but the same types of plant inclusions that are vitrinized also may, on occasion, be found in fusinized condition. Thus rodlets of medullosans, commonly demonstrable in vitrinized form in coal thin sections, occasionally are substantially opaque to transmitted light and have been essentially converted into fusain. Frequently fusinized rodlets of several types can be observed in maceration residues, such as are prepared for microfossil study, after they have been isolated from the vitrinized portion of the coal. Sometimes the rodlets are in place in secretory ducts of a piece of fusinized tissue. Although such occurrences emphasize the diversity of materials that may be fusinized, the greater amount of fusain is derived from walls of cellular tissues that originally must have been cellulosic or lignocellulosic in composition. Fusinized fragments also may be subcellular in size, and it is probable that opaque attritus, micrinite or the truly opaque residuum, is simply a very finely particulate or dispersed form of fusinized material.

Fusinized tissues generally show excellent preservation of cellular form. The walls appear normal in morphology, with little, if any, evidence of shrinkage or dimensional change. The fidelity of morphologic preservation is some-

LIBRARY

times very striking in comparison with the great alteration in chemical composition. Sometimes the finest microscopic details of scalariform pitting can be observed.

There seems to be no particular relationship between the botanical nature of the plants or of the tissues of plants to fusinization. The seeming preference for thick-walled (woody) tissues that has been remarked by various authors probably has another explanation, mentioned below, and it is believed that all the various tissues of different kinds of plants can be fusinized and contribute to the fusinized portion of coal although the more delicate tissues are not as easy to demonstrate.

Cell walls of fusinized tissues are strong in comparison with tissues of incipient vitrinization and are evidently able to resist plastic distortion. Nevertheless, the fusinized walls are competent only in proportion to their thickness, and they break with a sharp fracture when natural pressure stresses exceed their strength. Some of the "bogen" structure illustrated by various authors consists of such fractured cells. In bituminous coal, fusain fragments consisting of thick-walled cells (lumen area less than 30 per cent in tissue cross section) generally show little or no fracturing. On the other hand, tissues composed of thinner-walled cells are extensively fractured in the same coal, unless they have been protected and supported by permeating mineralization. A considerable amount of "soft" fusain consists of a dust or fragments of thinner-walled cells, apparently fragmented by ordinary compression in coalification.

The changes affected by fusinization result in the concentration of carbon and elimination of oxygen and hydrogen, to the extent that fusain closely resembles anthracite in its chemical composition. It is exceedingly resistant to chemical oxidation, and it is the only coal constituent for which a chemical method of determination has been devised.[15] Fusinized cell walls are very hard and exceedingly friable. Observed microscopically, they are seen to be brilliantly glistening and show evidence of smooth conchoidal fracture. The irregularity caused by cellular cavities dominates the megascopic appearance to show a dimly visible "fibrous" structure that is dark and lusterless in bands and lenses of a coal bed. In thin sections fusain is essentially opaque to transmitted light, and the appearance of the open cell lumens generally identifies it. Small areas in sections that approach ultimate thinness may show a grayish translucency, but the material is very similar to high-rank anthracite in lacking preferential transmission of color.

According to Seyler,[16] fusain shows the maximum reflectance and can be compared with the most altered vitrinized material, which has a reflectance number of nine.

The relation of fusinization to the whole coalification process is shown diagrammatically in the accompanying figure. The great change in composition of fusinized phyterals is indicated for the diagenetic or peat stage. So far as the writer is aware, there is no clear evidence that typical fusain is ever

[15] Fuchs, Gauger, Hsiao, and Wright (Pennsylvania State College Bull. 23, p. 43, 1938) indicate that the nitric acid oxidation of fusain differs from that of the rest of the coal and can be characterized as a zero-order reaction.

[16] Seyler, C. A., op. cit., see footnote 14.

influenced by metamorphic agencies, so a very slight slope is shown on the fusinization curve through most of the coalification sequence. Necessarily this is a tentative interpretation, and more careful studies should be planned to bear on this point directly.

Incomplete Fusinization.—The previous discussion has dealt with the petrologic character of typically vitrinized and typically fusinized materials. Another class of materials preserved in intermediate fashion is commonly present in coal, although generally in subordinate amounts. Even so, the intermediate mode of preservation offers some practical difficulty in petrographic study. Larger fragments of this nature have been referred to as semifusain, and the material has also been referred to as semifusinite. The more finely particulate occurrences were simply called "brown matter" by Thiessen.[17]

Tissues preserved in the form of semifusain evidently retained sufficient strength to partially withstand the pressure of compression. Distortion effects are evidenced by the cell walls being bent, but the lumens usually are not completely closed. Appearances of this type are frequently described as "bogen-structure." Most frequently semifusain exists as a transition phenomenon bridging uncompressed typical fusain and completely collapsed anthraxylon. Parallel gradation in optical translucency also exists and semifusain has a brownish translucency in ordinary sections, merging imperceptibly with the reddish translucent anthraxylon on one side and opaque fusain on the other.

The preservationally intermediate materials are difficult to classify into specific macerals, since they probably vary continuously in composition through the range from fusain to anthraxylon. For this reason they seem different from the vitrinite intermediates Seyler discusses, although it is conceivable they may show some similar variation in reflectance. The chief distinction would seem to be one of origin; Seyler's vitrinite intermediates are evidently different metamorphic ("metasomatic") forms, whereas the preservationally intermediate forms discussed here are regarded as diagenetic in origin, similar to fusain, and do not owe their presence to metamorphism.

The path of alteration of intermediate preservational forms is not indicated on the accompanying diagram, but their position presumably would lie between the main paths indicated for vitrinization and fusinization. It would be of much interest to determine how the incompletely fusinized materials are affected by metamorphic change, and at what stages the changes occur or are initiated. Judging by translucency, semifusain is apparently not present in anthracite, though at least some types of bogen-structure can be detected.

Studies of semifusain probably would do much to clarify the differences between typical vitrinization and fusinization processes. The selection of samples for such studies would be of critical importance, because complete transitions from one to the other typical form generally occur across band-like zones, which are, at the most, a few millimeters wide. Semifusain and typical fusain are virtually indistinguishable by megascopic observation, and for this reason microscopic methods would have to be employed.

[17] Thiessen, R., and Sprunk, G. C., Microscopic and petrographic studies of certain American coals: U. S. Bur. Mines Tech. Paper 564, p. 3, 1935.

THE RELATIONSHIP OF PETROGRAPHY TO COAL CLASSIFICATION.

Coal beds or commercial lots of coal contain varying proportions of the different petrographic materials, and it is evident that the characteristics of the coal will vary, depending on the effects the different materials have when used in mixtures. It is recognized that petrographic characteristics are not closely identified with the results of routine chemical procedures. Thus, petrographic determinations are needed, in conjunction with chemical and utilization tests, to define the nature of such mixtures. Data of this sort would eventually clarify the causes for the original differences as well as the causes for differences in coal relating to its potential uses. A coal classification employing these data would have much greater weight in predicting the value of coal resources.

The present standard sampling procedures are designed to provide data on the average composition of a coal bed or a commercial lot of coal. Volatile matter and fixed carbon values depend to a considerable extent on percentages of fusinized and waxy-resinous materials that are present in the sample, in addition to the metamorphic stage (rank) of the coal. Fusinized materials are naturally very rich in carbon and low in volatile matter, and concentrated waxy-resinous materials influence analytic results in the opposite direction. If both are present in an "average" concentration, they, of course, tend to counterbalance one another, and results from a series of coals of "average" petrographic composition would accord with degree of metamorphism. However, many coals are far wide of the average in concentrations of fusain or other allied materials. Beyond this, fusain concentrations can vary widely in coal from the same mine, depending on how a particular lot of coal has been treated and handled after mining. Consequently, some systematic effort should be made to estimate the actual petrographic composition to show to what extent the usual proximate and ultimate analyses are based on samples comparable petrologically, and, hence, to what extent the chemical results can be used for detailed comparison.

The specific effects of materials resulting from the three coalification processes at any of the various possible levels of metamorphic alteration on commercial-utilization properties or on laboratory-scale tests still are not well known. A few generalizations are possible, as, for example, with regard to volatile matter and fixed carbon, and more information will be developed as work progresses. Probably it will be necessary to test the effects of petrographic composition specifically in order to determine what concentrations may be critical for specific functions and in order to decide what subdivision of petrographic materials is most suitable for use as a standard in classification of coal by type. A generalized and practical approach to this problem is illustrated by the current "Standard Definitions for Commercial Varieties of Bituminous and Sub-bituminous Coals" adopted in 1939 by Committee D-5 of the American Society for Testing Materials and approved by the American Standards Association.

Petrographic composition influences the present standard classification of coal by rank, as indicated above, but these variables might be more properly

recognized in a separate type classification. A more adequate specification of coal requires combination of the variables resulting from genetic differences in materials (biologic and diagenetic) and the variables resulting from different metamorphic history. It is evident from the considerations presented in sections of the present paper that many of the practical aspects of type and rank in coal are very closely interrelated, and a considerable problem still exists as to how this can best be expressed by classification.

In this connection, mention should be made of Seyler's studies regarding "volatile displacement," [18] which is based on the idea of compensating for variations in coal occasioned by petrographic differences, so that the corrected analytic values correspond to a hypothetical coal at an equivalent stage of metamorphism and composed solely of vitrinized matter. Practical difficulties still exist that affect the general utility of the volatile displacement method, but it seems clear that the considerations that led to its proposal are valid and deserving of attention.

Type classification of coal has been reviewed recently by Rose [19] and by Cady [20] and need not be discussed further. Another recent summary of petrography and coal classification, with particular reference to practical uses, was prepared by Mackowsky and Abramski in 1943.[21] The reader is referred to these articles for additional discussion of these topics and for further references to the abundant literature.

Addendum.—A paper by Dulhunty, stressing ultramicroscopic physical alteration of coal and distinguishing both physical and chemical rank variation, has come to the writer's attention since the preceding discussion was written (see Dulhunty, J. A., Australian Jour. Sci., vol. 9, no. 4, pp. 133–137, Feb. 1947). The more precise viewpoint regarding rank probably will prove to be an advantage. For example, emphasis of physical features might show that coals with lustrous vitrain and translucent yellow waxy matter are more naturally related for purposes of classification.

SUMMARY.

The nature of coalification and its relationship to coal petrography has been discussed. The distinction between phyterals and macerals is pointed out, and the general process of coalification is resolved into three processes of more specific petrographic significance. The separate processes are called incorporation, vitrinization, and fusinization; each coal bed generally includes various proportions of materials derived by all three processes. Each process is discussed with particular reference to evidence supplied by study of coal

[18] Seyler, C. A., Petrology and the classification of coal: South Wales Inst. Eng. Proc., vol. 53, no. 4, pp. 254–327, 396–407, 1938.

[19] Rose, H. J., Classification of coal. Chapter 2, pp. 25–85: "Chemistry of Coal Utilization," vol. 1. Prepared by the Committee on the Chemical Utilization of Coal, Nat. Research Council, H. H. Lowry, Chairman and Editor. John Wiley & Sons, Inc., New York, 1945.

[20] Cady, G. H., Coal petrography. Chapter 3, pp. 86–131: "Chemistry of Coal Utilization," vol. 1, New York, 1945.

[21] Mackowsky, Marie-Therese, and Abramski, Carl, Kohlenpetrographische Untersuchungsmethoden und ihre praktische Anwendung. Feuerungstechnik, Zeitschrift für den Bau und Betrieb feuerungstechnischer Anlagen, Jahrg. 31, Heft 2, pp. 25–33 (February 15); Heft 3, pp. 49–64 (March 15), Berlin, 1943.

thin sections. Diagenetic and metamorphic agencies, together with initial differences in plant materials, are responsible for the train of events involved in coalification, but the influence of each agency on the three coalification processes differs greatly. Fusinized materials are formed very early in the diagenetic stage and are imperceptibly affected by metamorphism. Waxy-resinous materials are very slightly changed until the intensity of metamorphism is sufficient to alter the coal beyond high volatile bituminous rank. At this stage of natural devolatilization marked change is noted in the petrographic characteristics of the waxy-resinous components. This change probably has significance in regard to composition and properties of the coal. Vitrinization is chiefly induced by metamorphism, but the nature of the progressive changes cannot be assuredly indicated at the present time.

The separate processes of coalification can be defined at present only by reference to the petrologic characteristics of the differently preserved materials. A more fundamental understanding of the nature of the processes is highly desirable, particularly so in regard to vitrinization, since vitrinized material is so generally abundant. The coalification processes have essential bearing on improvement of type and rank classification systems.

U. S. GEOLOGICAL SURVEY,
330 U. S. NATIONAL MUSEUM,
WASHINGTON 25, D. C.,
Feb. 20, 1948.

REVIEW OF THE MINERAL INDUSTRIES OF LATIN AMERICA.[1]

SUMNER M. ANDERSON.

INTRODUCTION.

METAL mining in Middle and South America, as in the rest of the world, encountered in 1946 many obstacles to the adjustment to post-war conditions. Compared with the previous year, production increased for about ⅓ of the principal metals but only two of the large tonnage ores, bauxite and iron ore, were included in this group. Scarcity and increased cost of labor, strikes and other manifestations of social unrest, high taxation, burdensome legislation, and the continued scarcity of machinery and supplies, combined to offset, in most operations, the incentive offered by generally favorable demand and prices.

In the nonmetallic mineral field, production responded better to the favorable world markets for diamonds and Chilean nitrates and to favorable domestic markets for such minerals as have predominantly local rather than international demand.

Outstanding success was attained in improving the output of coal and crude petroleum. Petroleum refinery production increased in eight of the ten countries that have refineries.

BAUXITE.

In searching the field for a choice of outstanding developments, we find a healthy recovery from the short post-war slump in bauxite mining, with British Guiana and Surinam gaining in output 52 and 21 per cent, respectively, over the previous year. In each colony considerable attention was given to the examination of undeveloped deposits by engineers representing both the Reynolds Metal Co. and the Kaiser Corp. and the outlook for several years to come is good. Little was done in bauxite exploration in Jamaica or Haiti and ALCOA withdrew from the Dominican Republic as Reynolds Metal had in 1944. In Brazil the new aluminum plant of Electro-Quimaca Brazileira at Ouro Preto was unable to reduce its costs to a level competitive with imported metal and was closed.

IRON AND STEEL.

The National Iron and Steel plant at Volta Redonda, Brazil, came into production in mid-year and has been operating at about ½ capacity ever since. Chief obstacle in the way of full-scale operations is the procurement of ade-

[1] Presented at the annual meeting of the Pan-American Institute of Mining Engineering and Geology (United States Section), New York, February 18, 1948, by permission of the Director, Bureau of Mines, U. S. Department of the Interior.

quate quantities of coal, due primarily to deficiencies in transportation facilities. Some unforeseen difficulty is also said to have arisen in the local marketing of the steel products because of limitations of manufacturing plants and local changes in size specifications for steel rail. Iron ore production during the year is estimated to have reached a million tons.

In Mexico, where steel-making operations are also subject to limitations in the availability of coal, the industry continued to produce at about a normal rate, which falls far short of meeting the requirements of the country.

In Chile, the well known operations of Bethlehem Steel at El Tofo mines were stepped up some 43 per cent over 1945 to an output of 1,350,000 tons. The new Chilean Cía. de Acero del Pacífico started construction of a 180,000-ton steel plant on San Vincente Bay near Concepción. The company expects to start production in 1949 using ore from El Tofo mines, coal from Lota and Coronel, limestone from the Province of Coquimbo and electric energy from a plant at Abonico. The plant will be under American management and is expected to provide Chile with its basic iron and steel requirements.

In Peru, work progressed in the establishment of an industrial center for the Port of Chimbote. Among other developments in that area, the Government-owned Santa Corporation includes plans for a steel plant using electric instead of all-coke furnaces that will derive power from the 125,000 horsepower hydroelectric plant now under construction at Cañon del Pato. Iron ores are to come from the Marcona deposit near the coast and about 200 miles south of Lima. A highway has been completed connecting the Marcona deposit and the Bay of San Juan with the Pan American highway, and a contract has been granted for the building of port facilities at the Bay of San Juan.

In Colombia, the proposed Paz del Río iron and steel project is still in the planning stage and no date has been announced for the start of plant construction.

In Venezuela, the Bethlehem Steel Co. advanced its program for the development of the ore deposits at El Pao, but actual production is not anticipated before the end of 1949. A deep-water loading station, originally planned for a small island off the coast of Trinidad, was tentatively relocated to the southern coast of the Paría peninsula, near the municipality of Cristóbal Colón. Construction progressed on loading stations and warehouses at the Orinoco river port of San Félix, and on housing facilities and other essential installations at El Pao, 30 miles south. A highway was completed connecting the two localities. During this past year 1947 San Félix and El Pao were also connected by 35 miles of railroad which will eventually be doubled. The United States Steel Corporation explored concessions in the vicinity of Tucupita, in the Orinoco delta, but commercial development has not been undertaken to date.

NICKEL.

More nickel was produced by the United States Government-sponsored plant of the Nicaro Nickel Co. at Nicaro, Oriente Province, Cuba, in 1946 than at any time since it started operations in 1943, but the plant encountered several mechanical and technical difficulties and fell considerably short of at-

taining its rated annual capacity. The Nicaro contract with the Reconstruction Finance Corporation expired December 31, but was extended to March 31, 1947, and the plant was closed and offered for sale. This nickel project represented a cost to the United States Government of about $35,000,000 and produced, to the end of 1946, 34,966 metric tons of nickel oxide containing 26,859 tons of nickel plus cobalt and valued at about $16,000,000. Performance of the plant failed to demonstrate ability to operate at a profit on a competitive basis.

In Venezuela, the International Nickel Co. completed sampling of the garnierite deposit at Lorno de Hierro near San Pedras, in the State of Aragua. The deposit is reported to be of high tonnage and good grade and well suited to mechanized open-pit mining. Development of the property probably will depend on the results of research into certain metallurgical problems presented by this type of ore.

COPPER.

Cuba is the only country in Latin America that showed an appreciable increase in copper production in 1946, amounting to 25 per cent over that of 1945. The increase was developed from newly found reserves at Minas de Matahambre, the only copper property operating in the Republic in those years. Plans for reopening the old Candida, Dora, and Francisco mines, also in the Province of Pinar del Rio, were abandoned early in 1946 following geological investigations that yielded discouraging results. One other property in the same province, the Mercedes mine, is being developed for reopening by a Cuban company.

Copper production in Mexico was maintained at virtually the 1945 level only because the general strike that affected most mines during the first quarter was not applied against the Cananea Consolidated Copper Co., which operated Mexico's largest copper project throughout the year. Evidence of a better response to advanced prices became apparent in 1947.

Bolivian copper output maintained the modest but virtually constant level of the previous six years with the American Smelting & Refining Co.'s Corocoro mine contributing by far the largest portion of the total.

An 18 per cent drop in Chilean production was caused by strikes that closed Braden Copper Co.'s El Teniente plant during October and November and Chile Exploration Co.'s Chuquicamata plant during June; a serious water shortage that further reduced the output at El Teniente throughout December; and the complete shutdown throughout the year of the custom smelters at Chagres and Naltagua.

A 23 per cent drop in Peruvian production was the result of a shortage of mine labor and the continued decrease in the grade of ore from the important central-Peruvian copper districts of Cerro de Pasco, Morococha, Puquiococha, and Huaron; also the mining and milling of low grade copper ore at Cerro de Pasco was greatly curtailed in mid-1946 when the 800-ton concentrator, constructed during the war and used exclusively for the beneficiation of copper ores, was converted to the flotation of lead-zinc. The long downward trend may be arrested this year when the Cerro de Pasco Copper Corp.

expects to begin regular production at its Yauricocha copper-gold-silver mine, about 75 miles south of Oroya. The American Smelting & Refining Co. also is planning to bring into production, at an unannounced date, an extensive low-grade copper property near Toquepala, in southern Peru, by open-cut mining on a large scale, which should more than compensate for the decline in yield of its Quiruvilca mine in northern Peru. A copper refinery under construction at Oroya probably will not be completed before late this year or early 1949.

The small copper production of Ecuador, amounting to considerably less than 5,000 tons annually, ceased in 1946 following closing of the Cotopaxi Exploration Co.'s silver-gold-copper-lead mine and smelter at Macuchi in July.

LEAD AND ZINC.

Probably the outstanding event of the year 1946 in Mexico was the discovery of an important lead-zinc-silver orebody in the adjacent Concha and San Antonio mines in the Taxco district, Guerrero, at a time when the Minas de Guerrero mine in the same district was approaching exhaustion. In 1947, the A.S.&R., owner of the San Antonio mine, arranged with the owners of the Concha to operate both properties as a single unit and adopted plans to erect a mill. The new operation will considerably extend the life of the Taxco district. The importance of finds of this kind is emphasized by the 26 per cent decrease for Latin America as a whole in the production of lead and zinc from 1945 to 1946.

CADMIUM.

Production of cadmium in Mexico on a mine basis has long been a matter of speculation. Official statistics show only that portion recovered in flue dust, while much of the metal refined in and credited to the United States is taken from zinc ore mined and concentrated in Mexico. To arrive at a reasonable estimate of the actual Mexican output of cadmium, it was found from special inquiry in 1946 that all zinc concentrates exported contain an average of close to $\frac{3}{10}$ per cent cadmium, which should be added to the reported content of exported flue dust. Application of this formula shows an approximate mine-basis production of 2,250 metric tons in 1945, and 1,400 tons in 1946, accompanying the decline in zinc output and substantiating the belief that Mexico is second only to the United States in world production. Unfortunately it is impossible to trace the zinc concentrates after they enter the United States or to determine what portion of their contained cadmium is actually extracted.

GOLD AND SILVER.

Precious metal mining is too diversified and widespread to review in detail here. Latin America as a whole fell 6 per cent below the 1945 output of gold and dropped 22 per cent in silver. It should be noted that in Mexico, the world's largest producer of silver, internal economic factors plus fluctuations in the prices of base metals outweigh fluctuations in the price of silver as a

factor affecting output. The world's largest silver mine at Pachuca, the Real del Monte, was sold by the United States Smelting & Refining Co. to the Mexican Government in September 1947.

MISCELLANEOUS NON-METALLIC MINERALS.

Barite.—The nonmetallic mineral industries had a better year than metal mining. A regional increase of 52 per cent in the production of barite was brought about by initiation of a full-scale operation on Camamú Island, Bahia, Brazil.

Cement.—The cement industry tried to meet the urgent demand for construction materials by capacity operation of Latin American plants that gave an over-all increase in output of 13 per cent, but heavy increases in imports pointed out the shortages in local plant capacities. Production capacity in Mexico caught up with Mexican requirements this year (1948) for the first time, with 17 operating mills and 4 more under construction. Requirements have now reached 2,000,000 metric tons annually.

Salt.—The over-all large-tonnage recovery of salt increased 6 per cent in 1946.

Nitrate.—Chilean nitrate production, still benefiting from Germany's reduced synthetic nitrate industry, increased 18 per cent.

Diamonds.—A favorable world market for diamonds stimulated production in Brazil, British Guiana, and Venezuela, to a combined increase of 24 per cent as measured in quantity of carats.

Quartz Crystal.—The outstanding recession in nonmetallics was seen in the post-war slump in demand for quartz crystal, resulting in 1946 exports from Brazil amounting to less than a fourth of 1945 shipments. This restraint in demand is expected to continue.

Coal.—Coal production advanced 44 per cent with increases in Mexico, Peru and probably Colombia, overbalancing decreases in Brazil and Chile. In Peru, a decline in bituminous production was offset by an increase of 123 per cent in the output of anthracite.

Petroleum.—Only two countries, Venezuela and Mexico, increased their production of crude petroleum, but their advances far outweighed the slight recessions in Argentina, Colombia, Peru, Ecuador, Brazil and Trinidad. For the third consecutive year, Venezuela established a new all-time record and recent figures show that it has done so a fourth time in 1947 with production exceeding 434 million barrels. This figure is more than double Venezuela's output in 1939, and maintains Venezuela in the position of world's second largest producer. In 1947 Colombia also reached a new peak of 26 million barrels, supplanting the previous record of 1940.

Chile progressed in development of the world's farthest-south oil field on the Island of Tierra del Fuego. By the end of 1947, production of several wells had been shut-in pending completion of storage and dock facilities and studies of a proposed oil refinery to be located near Valparaiso.

SUMMARY.

In summary it seems appropriate to emphasize the mineral importance of the Middle and South American segment of our hemisphere by pointing out that the area in 1946 produced more than half the total world output of natural nitrates, quartz crystal, beryllium ore, antimony, and silver; and more than a quarter of the bauxite, bismuth, tin, vanadium, arsenic, copper, and tantalite. The area also produced about one-fifth of the world's supply of tungsten, zirconium, and crude petroleum, and smaller but important portions of chromite, lead, zinc, platinum, diamonds, fluorspar, graphite, and mica. The production potential is believed to be much higher than indicated by past performance for several strategic items; notably bauxite, chromite, copper, iron ore, manganese, nickel, titanium, vanadium, diamonds, coal, and petroleum. In most instances full and profitable exploitation of these resources is more dependent on the expansion of transportation facilities than on any other single factor.

MINERAL ECONOMIST, FOREIGN MINERAL BRANCH,
U. S. BUREAU OF MINES,
WASHINGTON, D. C.,
Feb. 14, 1948.

DISCUSSION AND COMMUNICATIONS

THE GENESIS OF INTRUSIVE MAGNETITE AND RELATED ORES.

Sir: The theory for the genesis of intrusive magnetite recently proposed by S. J. Shand [1] postulates (1) the differentiation of ferrous hydroxide from a basic silicate magma and (2) oxidation of the iron to magnetite by oxygen withdrawn from the hydroxyl ion of the ferrous hydroxide. The reaction also liberates water and hydrogen. An experiment by Berl and Von Taack is cited to prove the authenticity of the reaction.

There can be no question that if ferrous hydroxide is cooled from its dissociation temperature in a closed space, the atoms would not reassemble to form ferrous hydroxide; instead the oxygen would go to the iron to form a higher oxide, magnetite or hematite. This reaction is in strict accord with a corollary of Van't Hoff's law of mobile equilibrium, which states that in a cooling system, those reactions take place first that give out the greatest amount of heat.[2] The heat of formation of magnetite is 1117 kj.; of hematite, 798; of ferrous hydroxide, 568; and of water as a gas, 242 kj.[3]

The oxide of iron that would be formed under the conditions specified would appear to depend upon the quantity of available oxygen. The formation of a molecule of magnetite, as seen above, yields more heat than a molecule of hematite, but the yield per atom of iron is greater when hematite is formed (magnetite 372; hematite 399), therefore, the formation of magnetite implies a limited supply of oxygen.

There can be no hesitation in accepting the chemical reaction that produces magnetite from ferrous hydroxide, but this same law of chemical combination co-operating with the laws of gravitation and diffusion appears to preclude the possible existence of ferrous—or any other—hydroxide in a magma in depth.

The most acceptable theory for the origin of our planet formerly offered by astronomers implies that the earth may be regarded as the daughter of the sun. Recently Harlow Shapley [4] has suggested that the earth is a sister rather than a daughter of the sun. In either case the temperature of the earth at the beginning was probably not less than that of the surface of the sun at the present time, that is, too high to permit union of the atoms.

While in a fluid state the heavier elements would migrate toward the center of the earth and the lighter and gaseous ones in the opposite direction. When the temperature was lowered sufficiently to permit chemical combination of the elements, those in juxtaposition would combine, and in the order prescribed by the law cited above, that is, those combinations would take place first that give out the greatest amount of heat. The light and highly exothermic ele-

ments like the alkali metals, silicon, etc., nearest the oxygen envelope would be first to seize upon the oxygen; the heavier and less exothermic metals could form oxides only when thrown up into the oxygen envelope by turbulences and eruptions, such as we see on the surface of the sun. Iron oxide thus formed, falling by gravity, would in part be caught in the silicate zone, but under conceivable conditions, a part, as magnetite, would descend to the zone of the heavy silicates or below it, to be ejected later into the overlying terrane, when crustal movements provide means of escape.

In the early stages of the earth's development, hydrogen, owing to its low density and high diffusibility, would be remote from the zones of the metals which would render the formation of metallic hydroxides quite improbable.[5]

CHARLES HENRY WHITE.

SAN FRANCISCO, CALIF.,
Jan. 31, 1948.

REFERENCES.

1. Shand, S. J.: The genesis of intrusive magnetite and related ores. ECON. GEOL., vol. 42, no. 7, pp. 634–636, 1947.
2. White, C. H.: A theory for the concentration and distribution of copper in the earth's crust. ECON. GEOL., vol. 36, no. 1, 1941.
3. International Critical Tables, vol. 5, pp. 176–207, 1929.
4. Shapley, Harlow: On the astronomical dating of the earth's crust. Am. Jour. Sci., vol. 243–A, pp. 508–522, 1945.
5. For further discussion of the principles involved see: White, C. H., The abyssal *versus* the magmatic theory of ore genesis. ECON. GEOL., vol. 40, no. 5, pp. 336–344, 1945; and White, C. H., Why the sea is salt. Am. Jour. Sci., vol. 240, no. 10, pp. 714–724, 1942.

Sir: Mr. White, in the above statement, doubts the existence of ferrous hydroxide in a magma at depth. But in my note on the genesis of magnetite I referred specifically to the *residual liquid* from gabbroic magma, and I conceive this liquid to be rich in water and strong bases. Under these conditions I think ferrous hydroxide iron can only be held as a hydrosol, from which magnetite may be formed by self-oxidation, as in the experiment described by Berl and Von Taack. There is evidence from many rocks that magnetite is often a mineral of late crystallization; this was recognized by Spencer, Geijer, Colony, and others, as I pointed out.

The purpose of my note was to show that the genesis of magnetite (and indeed of other magmatic ores) is capable of a simple explanation which does not demand strong acids or mysterious "mineralizers" as carriers for the metal.

S. J. SHAND.

COLUMBIA UNIVERSITY,
NEW YORK CITY,
March 20, 1948.

REVIEWS

Geology and Ore Deposits of the Little Hatchet Mountains, Hidalgo and Grant Counties, New Mexico. By SAMUEL G. LASKY. Pp. 101; figs. 18 and 27 Plates. Prof. Paper 208, U. S. Geological Survey, Washington, D. C. 1947.

The Little Hatchet Mountains are in the southwest corner of New Mexico about 15 miles west of the jog in the international boundary. The north half of the Range in Grant County contains the Eureka silver-lead-zinc mining district and the south half in Hidalgo County contains the Sylvanite gold-mining district. Since the first locations, made in 1871, production has not been large, amounting to only about 60,000 tons of ore of an estimated value of $1,250,000. The geology of the area is, however, of unusual interest and the geological surveys by indicating that the northern or Eureka half of the Range is the faulted-off upward continuation of the southern or Sylvanite half of the Range have opened up possibilities of important future mining developments.

The Little Hatchet Mountains constitute a northward trending desert range completely encircled by Pleistocene and Recent alluvium. With minor exceptions all the sedimentary formations of the Range appear to be of Lower Cretaceous age. They consist of shore and near-shore deposits of shale, sandstone, limestone and conglomerate with which several thousand feet of basaltic lava flows and pyroclastics are interlayered. Total continuous thicknesses in various parts of the Range vary up to 21,000 feet. The igneous sequence is similar to that in the near-by Lordsburg district and almost identical with that at Santa Rita.

The Lower Cretaceous sediments and volcanics are intruded by diorite sills and by three stocks—monzonitic and granitic in composition. Each of the stocks is bordered by a contact metamorphic halo and is accompanied by satellite dikes. The age of these intrusions is Late Cretaceous or Early Tertiary. With these intrusions the ore deposits are believed to be genetically connected. Other igneous rocks of the area, many of them effusives, are younger than the ore deposits. In all 22 varieties of igneous rocks are recognized in the area.

Three broad folds trend northwestward to westward across the Range and all are broken by later faults. The most interesting and economically significant fault is the Copper Dick fault of great displacement which has resulted in a duplication of the full sedimentary sequence and of one of the stocks. As a result of this duplication by post-mineral faulting it is believed that the supposed barren zone between the Eureka and Sylvanite districts contains a deep mineralized zone and recommendations are made concerning the prospecting of this zone.

The Granite Pass stock and the Sylvanite monzonite stock both lying south of the Copper Dick fault are surrounded by considerable contact metamorphic aureoles which extend much farther from the intrusions in directions parallel to the bedding. Less extensive contact metamorphism surrounds the smaller monzonitic stock at Old Hachita north of the Copper Dick fault. The extent of the contact metamorphism is shown on the geologic map. Around the Sylvanite stock the contact metamorphic effects may extend over two miles from the intrusive in a direction

LIBRARY JUN 7 1948 KANSAS

parallel to the bedding. Metamorphism was not confined to the wall-rocks but in places affected the stocks themselves. Some magnetite, pyrite and chalcopyrite accompany the silicates of the contact metamorphic zones but these disseminated sulphides are not in commercial amounts.

In both the Eureka and Sylvanite districts the ore deposits lie within or near one of the three igneous stocks. Most of them occupy fractures following dikes. They appear to have formed nearly contemporaneously with the contact metamorphism. The typical ores of the Sylvanite district contain native gold, tellurides and minor sulphides, principally arsenopyrite and chalcopyrite, in a gangue of vein silicates, quartz and calcite. Typical ores of the Eureka district contain base-metal sulphides in a gangue mainly of manganosiderite and have yielded mainly lead, zinc and copper. The Sylvanite ores are classed as hypothermal and the Eureka ores as mesothermal but before the formation of the Copper Dick fault they are believed to have formed part of a continuous zone of hypogene mineralization. Some downward enrichment in both silver and copper also occurred.

Mineralization related to Miocene? volcanic rocks is recognizable but is of trivial economic importance.

The report is excellently and profusely illustrated.

EDSON S. BASTIN.

Rocks and Rock Minerals. By LOUIS V. PIRSSON. Third edition revised by ADOLPH KNOPF. 349 pages; 36 plates, 72 figures. New York, John Wiley & Sons, 1947. Price $4.00.

In the third edition of this excellent book on lithology, the subject matter, the method of treatment and much of the text remain much as they were in the preceding edition. There is considerable rearrangement of the text, and there are numerous revisions and some changes in the illustrations. A few small omissions of the older text and some additions have been made. The classification of the metamorphic rocks has been modified and sedimentary rocks entirely rewritten. These revisions make the book a modern treatment of the subject.

The book is intended as a text for the study of rocks in the field and with hand specimens. The first part deals with general considerations and the composition of the earth's crust. The second part describes the rock minerals and gives methods and tables for their identification. The main part classifies and describes rocks and gives some data on their occurrence, association, texture, structure and origin. The final section gives tables for the determination of rocks.

One can find little fault with the text. However, the reviewer believes that the discussion of the order of crystallization in igneous rocks does not take enough account of our newer knowledge on this subject and especially the physical chemistry of the crystallization of magmas.

The common practice of teaching elementary students that orthoclase has the composition $KAlSi_3O_8$ leads to a serious misunderstanding of rocks, even admitting that some simplification must be made for elementary students. Most orthoclase and microcline contains from ten to over fifty per cent of $NaAlSi_3O_8$ besides smaller amounts of other constituents. I find great difficulty in getting students who have learned the simplified formula for orthoclase to accept the more complicated and true composition. The same criticism applies to many other minerals.

The chemical formulas given for some of the minerals would probably not be accepted by modern mineralogists. Muscovite is given as $H_2KAl_3(SiO_4)_3$; it should be $KAl_2(AlSi_3)O_{10}(OH)_2$.

ESPER S. LARSEN, JR.

BOOKS RECEIVED.

ALAN T. BRODERICK.

Publications of the Instituto Geológico y Minero de España (Geological and Mining Institute of Spain). Madrid, 1941 to 1946.

Mapa Geológico de Espanã (Geologic Map of Spain). *Scale 1:50,000, contours at 20 meters, colored, divided into 10 × 20 minute sheets.*

Each of the following bulletins contains 25 to 80 pages of text covering geology, hydrology and mineral products of its sheet, and is illustrated by photographs, inserts, colored geologic maps and cross sections.

No. 71-H. Explicación de la Hoja No. 813, Valdepeñas (Explanation of the Valdepeñas Sheet No. 812). DIEGO TEMPLADO AND A. DE ALVARADO.

No. 73-H. Sheet No. 389, Tarrega. AGUSTÍN MARÍN, M. L. MANDULEY AND J. R. BATALLER.

No. 76-H. Sheet No. 558, Villaviciosa de Odón. A. DE GÁLVEZ-CAÑERO AND L. JORDANA SOLER.

No. 78-H. Sheet No. 627, Talavera de la Reina. D. TEMPLADO MARTÍNEZ, J. MESEGUER PARDO AND J. CANTOS SÁIZ.

No. 79-H. Sheet No. 764, Munera. JOSÉ DE GOROSTÍZAGA AND E. DUPUY DE LÔME.

No. 82-H. Sheet No. 172, Allo. MANUEL DE CINCÚNEGUI, ALFONSO DEL VALLE AND JOAQUÍN MENDIZÁBAL.

No. 83-H. Sheet No. 390, Cervera. AGUSTÍN MARÍN, J. R. BATALLER AND M. L. MANDULEY.

No. 85-H. Sheet No. 742, La Roda. E. DUPUY DE LÔME, JOSÉ DE GOROSTÍZAGA AND PEDRO DE NOVO.

No. 86-H. Sheet No. 603, Escalona. D. TEMPLADO MARTÍNEZ, J. MESEGUER PARDO AND J. CANTOS SÁIZ.

No. 87-H. Sheet No. 605, Aranjuez. D. TEMPLADO MARTÍNEZ, J. MESEGUER PARDO AND J. CANTOS SÁIZ.

No. 88-H. Sheet No. 608, Huete. J. A. KINDELÁN.

No. 89-H. Sheet No. 604, Villaluenga. D. TEMPLADO MARTÍNEZ, J. MESEGUER PARDO AND J. CANTOS FIGUEROLA.

No. 90-H. Sheet No. 872, Alicante. D. TEMPLADO MARTÍNEZ AND J. MESEGUER PARDO.

No. 91-H. Sheet No. 628, Torrijos. D. TEMPLADO MARTÍNEZ, J. MESEGUER PARDO AND J. CANTOS SÁIZ.

No. 92-H. Sheet No. 914, Guardamar del Segura. D. TEMPLADO MARTÍNEZ AND J. MESEGUER PARDO.

No. 93-H. Sheet No. 607, Tarancón. J. A. KINDELÁN.

No. 94-H. Sheet No. 137, Miranda de Ebro. JOAQUÍN MENDIZÁBAL, ANTONIO COMBA, JOSÉ MARÍA RÍOS, ANTONIO ALMELA AND JULIO GARRIDO.

No. 95-H. Sheet No. 935, Torrevieja. D. TEMPLADO MARTÍNEZ AND J. MESEGUER PARDO.

No. 97-H. Sheet No. 393, Mataró. ALFONSO DE ALVARADO, M. SAN MIGUEL DE LA CÁMARA AND J. R. BATALLER.

No. 100-H. Sheet No. 360, Bellvis. L. SOLÉ SABARÍS AND N. LLOPIS LLADÓ.

No. 101-H. Sheet No. 753, Miajadas. I. ROSO DE LUNA AND F. HERNÁNDEZ-PACHECO.

No. 107-H. Sheet No. 346, Aranda de Duero. M. SAN MIGUEL DE LA CÁMARA.

Datos para el Estudio de las Hojas del Mapa Geológico, Gijón y Oviedo (Data for the Study of the Geological Map Sheets of Gijón and Oviedo). P. H. SAMPELAYO. Pp. 111; pls. 17.

Memoirs

El Sistema Siluriano (The Silurian System). P. HERNÁNDEZ SAMPELAYO. **Part I.** Pp. 592; illustrations. *Stratigraphy, structure of the Silurian rocks in Spain; colored geological map of the Segovia, Guadalajara, Hespericas and Guadarrama area, scale 1:400,000.* **Part II.** Pp. 848. *Listing of Silurian species, each with dates and authors who described them, followed by a chronologic listing of authors.*

La Interpretación Geológica de las Mediciones Geofísicas Aplicadas a la Prospección (The Geological Interpretation of Geophysical Measurements Applied to Prospecting). J. G. SIÑERIZ. Pp. 573; figs. 87; pls. 37. *Results of geophysical (magnetic, radioactive, electric, seismic) investigation of geologic problems in Spain.*

Criaderos de Hierro de España (Iron Deposits of Spain): Hierros de Córdoba y Jaen. A. CARBONELL T.-F. **Hierros de Sevilla.** EDUARDO CARVAJAL. Pp. 454; innumerable maps, photos and figures. *Descriptions of the many small mines and prospects in these districts.*

Bibliography of the Geology and Water Resources of the Island of Hawaii. G. A. MACDONALD. Pp. 191. Hawaii Div. Hydrography, Bull. 10. Honolulu, 1947. *Annotated.*

Geology and Ground-Water Resources of the Island of Molokai, Hawaii. H. T. STEARNS AND G. A. MACDONALD. Pp. 113; pls. 15; figs. 18; colored geol. map, 1:62,500, 50 ft. contours. Hawaii Div. Hydrology, Bull. 11. Honolulu, 1947.

Report, United States Delegation, Second Pan-American Congress of Mining Engineering and Geology. Pp. 47. U. S. Section, Pan-American Inst. Min. Eng. and Geol., Tech. Paper No. 5. New York, 1947. *Report on 1946 meeting held in Petropolis, Brazil.*

The Bauxite Deposits of the Boolarra-Mirboo North Area, South Gippsland, Victoria. H. G. RAGGATT, H. B. OWEN AND E. S. HILLS. Pp. 73; figs. 2; pls. 19. Australia Dept. of Supply and Shipping, Mineral Resources Survey, Bull. No. 14, Geol. Series No. 5. Canberra, 1945. *Tests on 5 of 24 known deposits show 735,500 long tons of 51% alumina, 8% silica, 7% ferric oxides, 5% titania. Deposits derived by alteration of Oligocene or Miocene olivine basalt tuffs under aqueous conditions in hot climate. Authors disagree as to whether deposits are due to direct surface weathering or to percolation of ground-waters high in organic acids. Main mineral is gibbsite, no diaspore or bohmite present.*

British Regional Geology, London and Thames Valley (2nd Edition). R. L. SHERLOCK. Pp. 69; figs. 24; pls. 5. Geol. Survey and Museum of Great Britain. London, 1947.

Geology of the Country around Weymouth, Swanage, Corfe and Lulworth. W. J. ARKELL. Pp. 385; figs. 84; pls. 19, including colored, not contoured, geol. map, 3″ = 1 mile. Great Britain Geol. Survey Memoir. London, 1947. *Detailed report, principally on stratigraphy and paleontology, of type region of Kimmeridgian, Portlandian and Purbeckian rocks.*

Foraminifera in the Permian Rocks of Australia. IRENE CRESPIN. Pp. 31; pls. 2; map 1. Australia Dept. of Supply and Shipping, Bureau of Mineral Survey, Bull. No. 15, Paleont. Series No. 5. Canberra, 1947.

Composition and Properties of Petroleum in West Virginia. A. J. HEADLEE, R. E. MCCLELLAND, E. J. BALL AND H. H. HESS. Pp. 15; tbls. 7; photo 1. W. Virginia Geological and Economic Survey Report of Investigations No. 3-A. Morgantown, 1947. *Fractional distillation, aromatic content analyses.*

Annual Coal Report and Non-Metallic Mineral Report with Directories of Reporting Firms, 1946. M. S. KLEIN, G. W. WHITE AND G. C. GAMBS. Pp. 105; tbls. 30; charts 3; map, 1. Ohio Dept. Industrial Relations. Columbus, 1947. *Statistics. Map of Ohio at 1″—8 miles, shows non-metallic mineral deposits (oil and gas omitted).*

Pumice Aggregate in New Mexico, Its Uses and Potentialities. D. M. CLIPPINGER AND W. E. GAY. Pp. 56; figs. 7; pls. 18; tbls. 17. New Mexico Bur. Mines and Mineral Resources Bull. 28. Socorro, 1947. *Methods of testing and results which show that pumice helps make strong, light, sound-absorptive and insulating concrete and plasters; is useful in soil conditioning and hydroponics.*

Kansas Geological Survey.

Bull. 70, Part 4. Cemented Sandstones of the Dakota and Kiowa Formations in Kansas. ADA SWINEFORD. Pp. 50; figs. 3; pls. 7; tbls. 5. Lawrence, 1947. *Carbonate and silica-cemented sands from 31 localities were studied petrographically, chemically. Cementation believed to have been penecontemporaneous with marine deposition.*

Bull. 70, Part 5. Magnetic Survey of Southeastern Crawford County, Kansas. R. M. DREYER. Pp. 9; pls. 3, including magnetic and structure contour maps, scale 1.5″ = 1 mile. Lawrence, 1947. *Inverse relationship of magnetic and structural contours due to thinning of shallow-seated magnetic strata along anticlines. Other geophysical methods not applicable to Tri-State district problems. Drilling of several inferred structures recommended.*

La Terre et l'Univers qui l'environne. C. L. SAGUI. Pp. 69; figs. 12. Publicaciones del Instituto de Fisiografía y Geologia No. 31. Rosario, Argentina, 1947. *A mathematical approach to the age of the earth, based on considerations of earthquake energies, cyclonic winds, solar energy and the earth's gravitational field.*

LIBRARY
JUN 7 1948
MANHATTAN
KANSAS

SCIENTIFIC NOTES AND NEWS

The American Association of Petroleum Geologists announces the recipients of the President's Award to be L. L. Sloss of Northwestern University, and W. M. Laird of the North Dakota Geological Survey. The award was presented at the annual meeting of the A. A. P. G. in Denver, on April 27th.

The Council of the Society of Economic Geologists has decided to continue the practice of alternate annual meetings between the Geological Society of America and the American Institute of Mining and Metallurgical Engineers. Consequently, they are planning to hold the next annual meeting at San Francisco in February 1949 jointly with the Mining Geology Committee of the Institute.

Economic Geology has decided to offer student-rate subscriptions at a reduced rate to bona fide students in geology in the colleges and universities of North America. This rate is $3.00 per year and 30 cents extra for postage to addresses outside of the United States in North America and can be obtained by writing for an application form to M. M. Leighton, Business Manager, Economic Geology Publishing Co., 100 Natural Resources Bldg., Urbana, Ill. Each application should be certified by the Chairman of the Department of Geology. Departmental Chairmen are requested to post a notice to this effect in their geology buildings.

The Mining and Geology Division of the Natural Resources Section, General Headquarters, Supreme Commander for the Allied Powers, has been issuing a number of reports dealing with the ore deposits of Japan. The last reports to be published are: No. 98, *Iron Sand Resources of Japan;* No. 99, *Ishikari Coal Field, Hokkaido;* and No. 103, *The Coal Fields of Kyrushu.* Because of the limited number of copies which can be furnished to the Department of the Army, distribution to specialized agencies cannot be complete. The complete list of publications to date can be found in the back of Report No. 103. Government agencies, colleges, industrial organizations and individuals in the United States who are interested in obtaining any of them should address requests to the Chief, Civil Affairs Division, Special Staff, United States Army, Washington 25, D. C.

Ralph W. Stone, charter member of S. E. G., retired from the Pennsylvania Topographic and Geologic Survey, is teaching geology at Wilson College, Chambersburg, Pa., this semester. On March 10 he was convocation lecturer at the college on Local Geology and Caves, and on April 3 he addressed the National Speleological Society meeting in Washington, D. C., on The Origin of Caves.

The S. F. Emmons Memorial Fellowship for the academic year 1948–49, carrying a stipend of $1,500.00, has been awarded to Peter Joralemon who will pursue his investigation at Harvard University.

Potash has been discovered in 8 drill holes in Canada in association with salt beds that underlie an area in Saskatchewan extending northeast from near the international boundary south of Regina to across the Alberta line. The beds range from 2½ to 14 feet thick at depths from 3,466 to 7,677 feet. The greatest concentration is in an 11-foot bed of sylvite and halite carrying the equivalent of 21.64% K_2O.

The Los Angeles Mineralogical Society were the guests of Dudley M. Davis, Chief Engineer-Geologist of Anaconda Copper Mining Company's Darwin Mines,

at Darwin, Calif., on February 22, where opportunity was afforded of visiting the mine and making collections from the oxidized lead, zinc, copper, silver, and tungsten ores.

KAR VER STEEG, of the Department of Geology and Geography of the College of Wooster, Wooster, Ohio, is marking his twenty-fifth year of service to the College this spring. In honor of this occasion a group of his former students organized two formal sessions, one on the place and content of geology in the liberal arts college, and the other of papers contributed by some of Dr. Ver Steeg's former students in the fields of geomorphology and oil geology. These sessions were held at Wooster on May 7, 8, and 9, with a dinner on May 7.

WILLIAM JAMES is now Director of Mineral Resources at Regina, Saskatchewan.

In the belief that the friends of Dr. H. Foster Bain are shocked by his sudden passing here, I am taking the liberty to pass on the circumstances surrounding the tragic event.

Dr. Bain has been closely identified with the mineral industry in the Far East, and was adviser in mining from 1936 to 1941 to the late President Manuel Quezón of the Philippines. During this pre-war period, great progress was made in the development of the mineral industry in the Philippines, and much must be attributed to the far-sighted policies established and maintained by President Quezón, as thoughtfully advised by Dr. Bain. At the same time, Dr. Bain was often consulted by the Governments of Japan and China, and he is particularly known for the technical part he played in the development of the Manchurian steel industry.

With the fall of the Philippines in 1941 Dr. Bain was interned in Santo Tomás internment camp and in 1943 was repatriated to the United States on the Gripsholm. From 1943 up to his recent departure it is understood Dr. Bain had been delegated by the Government to undertake a study of the iron and steel industry of our west.

In the fall of last year, the services of Dr. Bain were contracted by a large American mining company to conduct negotiations for a property here in the Philippines. Dr. Bain arrived here in mid-November and after carrying negotiations to an advanced stage he returned to New York in early January for a week's consultation, at which time he was fortunately able to see his family. Dr. Bain again returned to the Philippines in mid-February, and with negotiations nearly completed he was thinking of his return home.

In the afternoon of March 9, Dr. Bain in apparently good health attended a movie. About 4:30 P.M. he suddenly fainted in his seat and was transferred to Santo Tomás hospital where he passed away at 7:15 P.M. without regaining consciousness. Death is attributed to cerebral hemorrhage. At Dr. Bain's specific request as advised by Mrs. Bain, the body was cremated and the ashes were distributed by airplane over Manila Bay at 6:00 P.M. March 12, just at sunset—the time of day Dr. Bain loved so well, when the fiery red sun disappears behind the usual beautiful cloud-formations over Bataan Peninsula and the Island of Corregidor at the mouth of Manila Bay.

Thus ended the life of another great American mining engineer and geologist whose services and contributions to the mineral industry in the Far East are exceeded only perhaps by the life-long contributions, under great physical handicaps, of the late Amadeus Grabau in China. Dr. Bain leaves many sincere friends in the Orient and the world over.

EARL M. IRVING.